**Urban waste for biomethane grid injection and transport in urban areas**

**Project No: IEE/10/251**

# *Biomethane use for cities: grid injection & transport in City of Zagreb/Croatia*

FINAL DRAFT

***WP 5 – Task 5.2/D 5.2***

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# Contents

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The members of the Biogas & Biomethane Production task force are:

1. Ivan Frančić, Ministry of Maritime Affairs, Transport and Infrastructure
2. Branka Pivčević Novak, Ministry of Environmental and Nature Protection
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# Abbreviations

| | |
|---|---|
| CNG | compressed natural gas |
| PJ | peta joule |
| BCM | billion cubic meters |
| Mcm | million cubic meters |
| AD | anaerobic digestion |
| BGP | biogas plant |
| BGUP | biogas upgrading plant |
| BMW | biodegradable municipal waste |
| $CH_4$ | methane |
| CHP | combined heat and power |
| $CO_2$ | carbon dioxide |
| CWM | centre for waste management |
| DM | dry matter content |
| $L_{org}$ | organic load [$kg_{oDM}/m^3{}_R*d$] |
| MSW | municipal solid waste |
| oDM | organic dry matter content |
| RES | renewable energy sources |
| $t_R$ | retention time [d] |
| $Y_{gas}$ | specific biogas yield [$m^3{}_N/kg_{oDM}$] |
| $Y_{CH4}$ | specific methane yield [$m^3{}_N/kg_{oDM}$] |
| WEO | waste edible oil |
| WWTP | waste water treatment plant |

# 1 Introduction

Work Package 5 focuses on the third step in the WtB chain: on biomethane use. Core of this WP is the set-up of "Biomethane Use Task Forces" (Biomethane TF) in the City of zagreb and the organisation of 4 Biomethane TF meetings.

The objective is to define the best suitable market for biomethane in City of Zagreb. This was done by investigating the possibility of utilisation of biomethane as biofuel (compressed biomethane - CBM), grid injection, or both. Problems related to biomethane grid access were defined and solutions are be proposed.

The final output of the Wp5 is a Biomethane use concept for City of Zagreb. This includes a comparison of advantages and disadvantages of biomethane grid injection and as transport fuel in City of zagreb. The legal requirements of biomethane grid injection and for biomethane filling stations are described. A proposal for best solutions of biomethane use and strategies on how to create a sustainable demand for biomethane are made.

# 2 Overview of biogas and gas supply

In Croatia, natural gas is produced from 17 onshore and 9 offshore gas fields meeting 69.9 percent of total domestic demand. More than half of total gas production has been gained from the Adriatic seabed whilst the largest share of gas produced in the Pannonian area is coming from the fields Molve and Kalinovac. They include the units for processing and preparation of gas or transportation – Central gas stations Molve I, II and III.

Natural gas transportation is a regulated energy activity performed as a public service and represents the primary activity of Plinacro Ltd company, which is the owner and operator of the gas transport system.

In 2011, 3 309 billion cubic meters of natural gas were transported, of which 2.99 billion cubic meters from the entry to exit measuring-reduction stations, and 319 million cubic meters to the underground storage Okoli. At the system level, maximum transport of 13 581 207 cubic meters per day was achieved in 2011.

Croatia will encourage the production and use of biogas, domestic production of biogas plants and the construction of distributed energy resources (usable for farms themselves, but also for the local community) for disposal of waste from agricultural production, reduction of greenhouse gas emissions, but also promote the development of agricultural economy.

The Republic of Croatia has set a goal to produce approximately 2.6 PJ of energy from biogas or about 100 million $m^3$ of biogas in the year 2020 (the equivalent of at least 20% of the total livestock).

The Energy Development Strategy states that the Republic of Croatia, due to favourable effects on the reduction of emissions into the environment, will encourage the use of compressed natural gas (CNG) in transport. Place of its use are truck corridors (blue corridors) and city buses, as well as car traffic. Application of CNG in traffic opens the possibility of application of compressed biomethane, which will be especially incentivised, because it facilitates the fulfilment of obligations of renewable energy sources in transport.

Today, biogas is recognized in legislation that describes biofuels, but its use in production or transportation is still not stimulated.

Zagreb Municipal Transit System or ZET (Zagrebački Električni Tramvaj) is a branch of Zagreb Holding specialized for passenger transportation in the city of Zagreb (trams, buses). In 2009, it introduced buses on CNG that has increased demand for CNG by tenfold.

In Croatia, there are currently three CNG filling stations in operation (Zagreb, Ivanić-Grad and Rijeka) and one under construction (Zagreb).

## *2.1 Total natural gas supply in Croatia*

Total natural gas supply in Croatia in 2011 totalled 3165.0 million cubic meters. Natural gas production totalled 2471.4 Mcm. Natural gas import totalled 876.1 Mcm, while export totalled 258.6 million cubic meters.

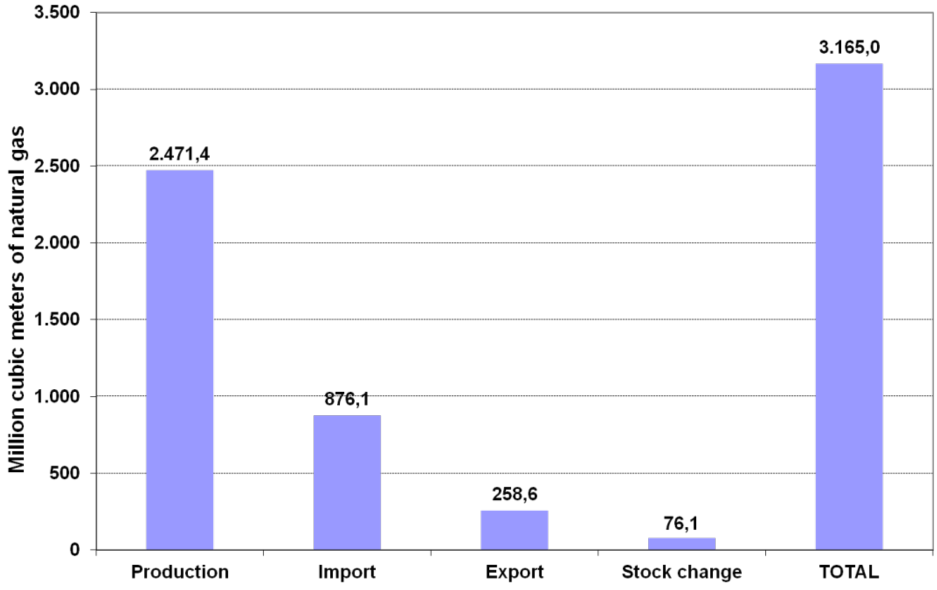



**Figure 1. Total natural gas supply in Croatia in 2011 (by source)**

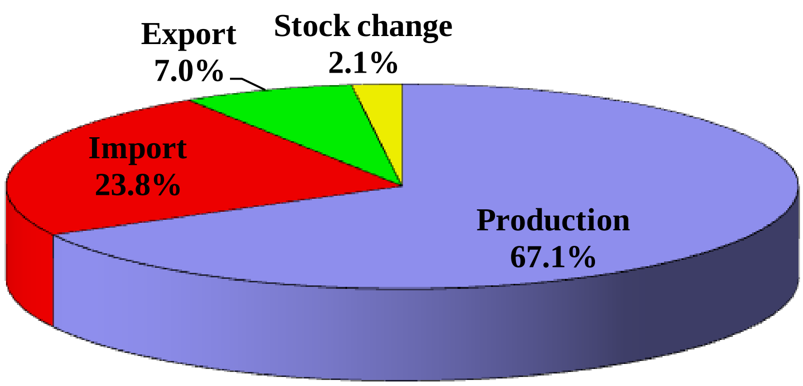



**Figure 2. Total natural gas supply in Croatia in 2011 (by source) - shares**

Total natural gas consumption in transformation sector in Croatia in 2011 totalled 1212.0 million cubic meters. The largest share of the gas consumed is used in the public cogeneration plants, 53.8 percent, and in the industrial cogeneration plants, 25.0 percent.

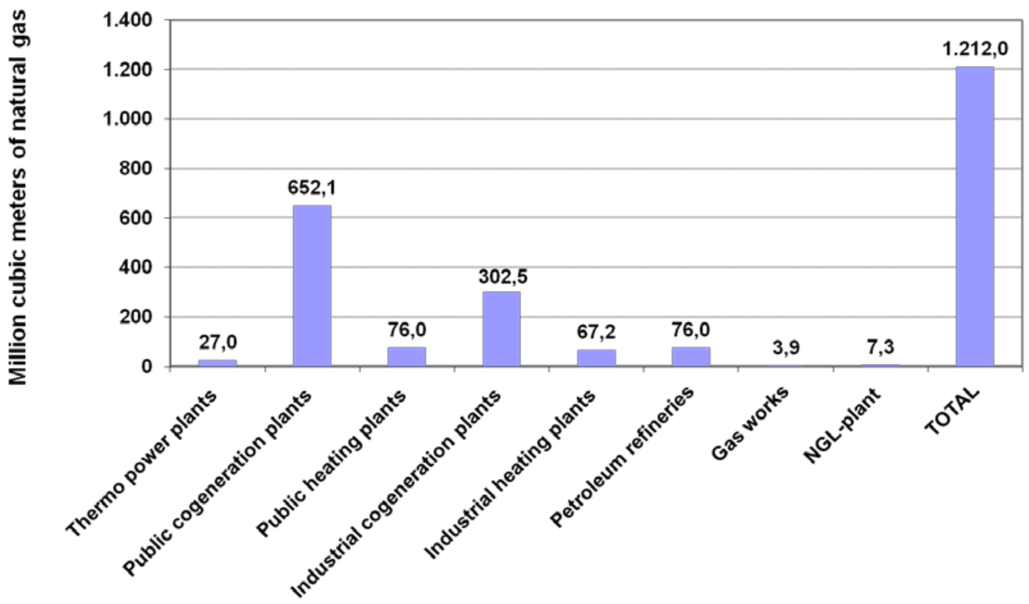



**Figure 3. Total natural gas transformation sector in Croatia in 2011**

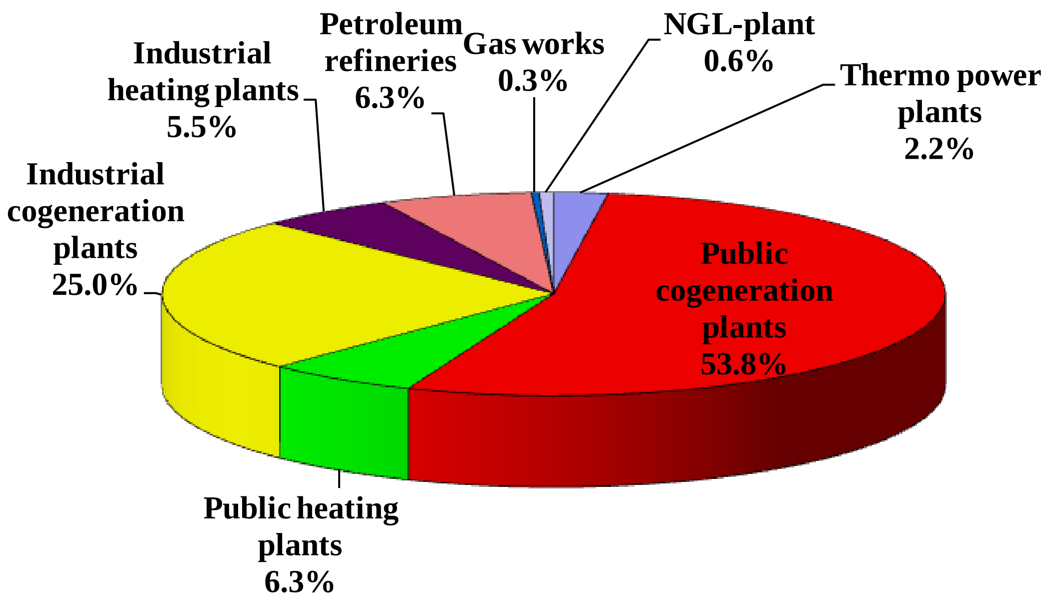



**Figure 4. Total natural gas transformation sector in Croatia in 2011 - shares**

Total primary energy supply in Croatia totalled 383.65 PJ in 2011. Natural gas share in total primary energy supply was 28.3 percent.

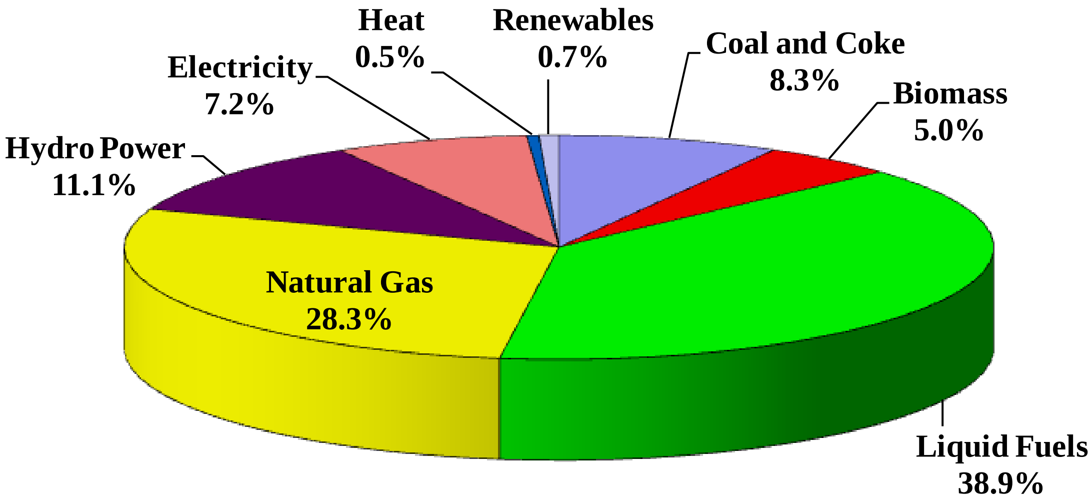



**Figure 5. Total primary energy supply in Croatia in 2011 - shares**

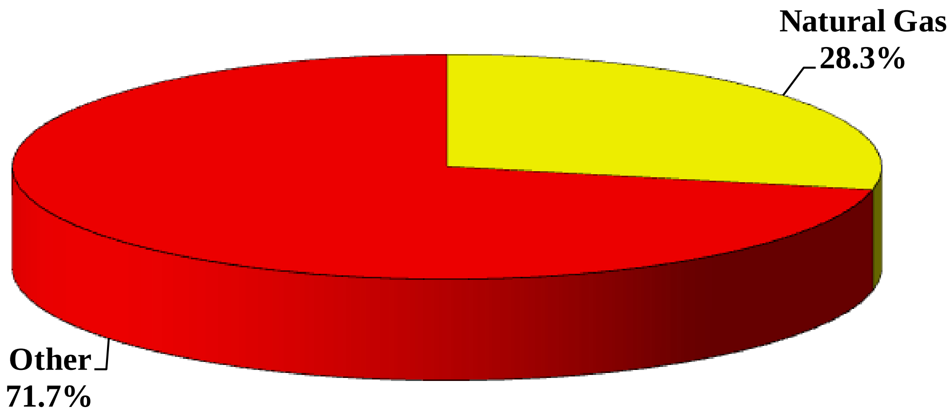



**Figure 6. Natural gas share in total primary energy supply in Croatia in 2011**

## *2.2 Final natural gas consumption in Croatia*

Final natural gas consumption in Croatia in 2011 totalled 1770 Mcm. The largest share in total natural gas consumption was in household sector, and then for non-energy use, industry, services, etc.

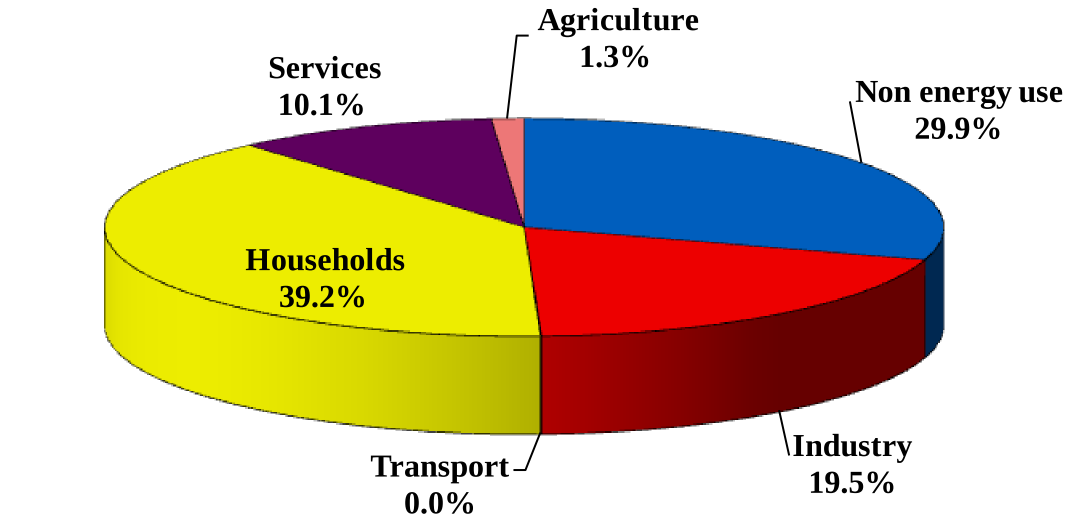



**Figure 7. Final natural gas consumption in Croatia in 2011 (by sector)**

Final energy consumption in Croatia in 2011 totalled 259.19 PJ. Gaseous fuels consumption in that year totalled 40.90 PJ, which represents 15.8 percent of total energy consumption.

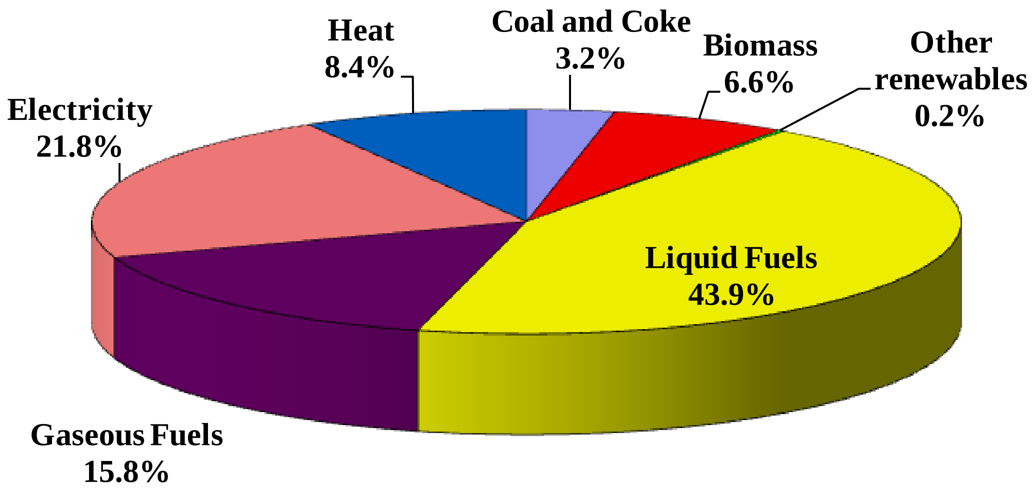



**Figure 8. Final energy consumption in Croatia in 2011 (by fuels)**

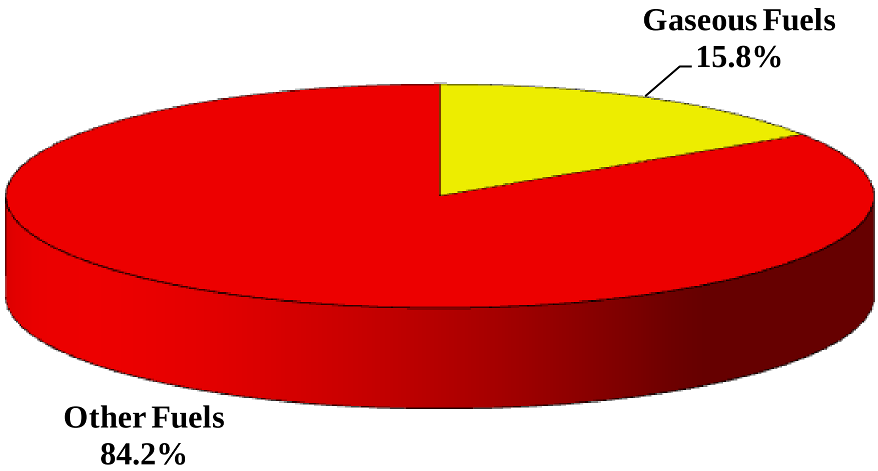



**Figure 9. Final energy consumption in Croatia in 2011 (by fuels)**

### *2.3 Final natural gas consumption in City of Zagreb*

Total energy consumption in the city of Zagreb in 2011 amounted to 61.8 PJ. Natural gas accounts for the largest share in the total consumption of 57% (35 PJ or 1.0 BCM) and then liquid fuels with a share of 34% (21 PJ) and other fuels with much smaller shares. 63% (0.65 BCM) of the total consumption of natural gas is consumed in the transformation of energy (electricity and heat production) while in the final consumption 36% of total consumption (0.3716 BCM) is consumed.

Final energy consumption in City of Zagreb in 2011 totalled 48.38 PJ, of which 40.9 percent was consumed in households, 25 percent in transport sector, 18.5 percent in industry sector, 15.4 percent in service sector, and 0.2 percent for agriculture.

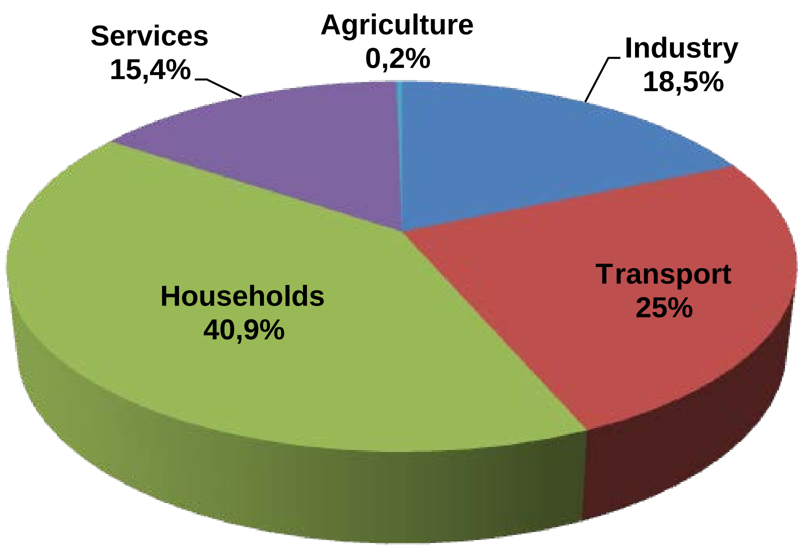



**Figure 10. Final energy consumption in City of Zagreb in 2011 (by sector)**

Natural gas consumption in City of Zagreb in 2011 totalled 12.63 PJ (371, 6 million $m^3$), which represents 26.1 percent of final energy consumption.

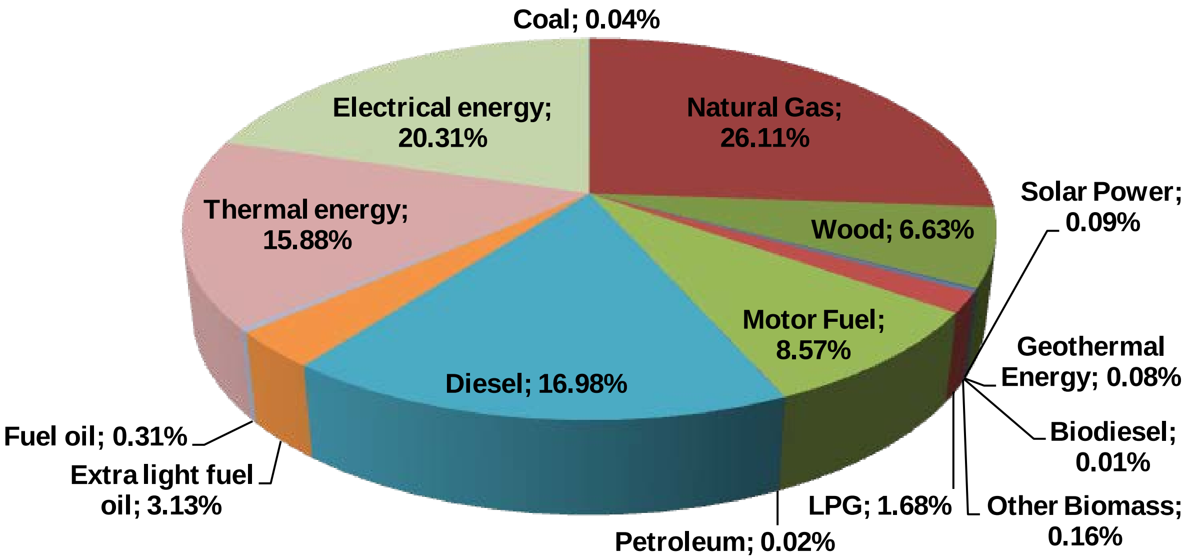



**Figure 11. Final energy consumption in City of Zagreb in 2011 (by fuels)**

Natural gas is mostly used in households with a share of 66% (8.3 PJ or 245 mil $m^3$.), followed by industry with a share of 27% (3.5 PJ or 102 mil. $m^3$) and service sector with a share of 7% (0.9 PJ or 26 million $m^3$ ). The share of transport with achieved consumption of 0.8 million $m^3$ is negligible.

## *2.4 Natural gas in transport – Croatia and City of Zagreb*

Final energy consumption in transport in Croatia in 2011 totalled 84.97 PJ. Natural gas consumption in transport sector totalled 0.03 PJ, which represents only 0.04 percent of total energy consumption in transport sector in Croatia in 2011.

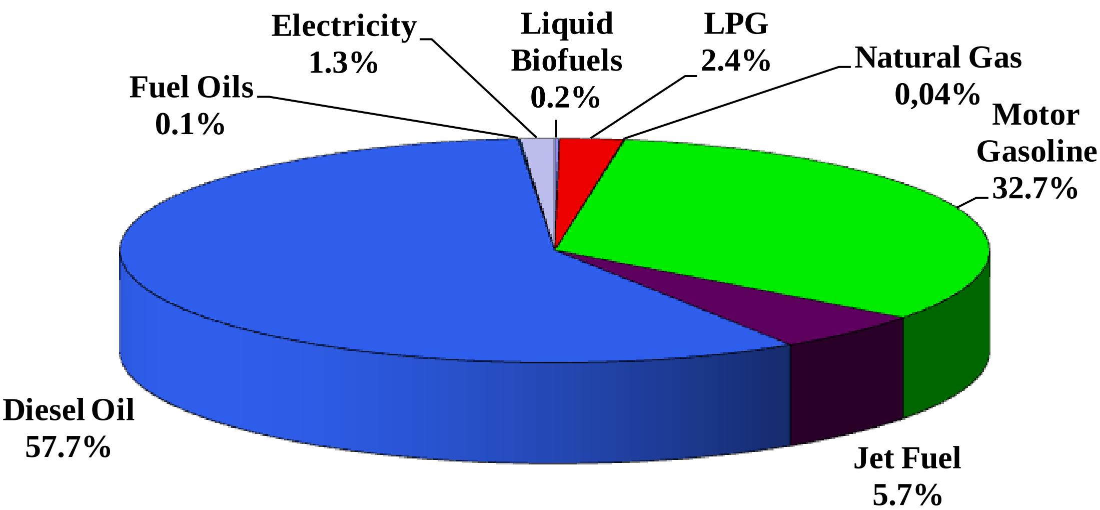



**Figure 12. Final energy consumption in transport in Croatia in 2011 (by fuels)**

Final energy consumption in transport in the City of Zagreb in 2011 totalled 12.01 PJ. Natural gas consumption in transport sector totalled 0.027 PJ (0.8 mil. m3), which represents only 0.22 percent of total energy consumption in transport sector in the City of Zagreb in 2011.

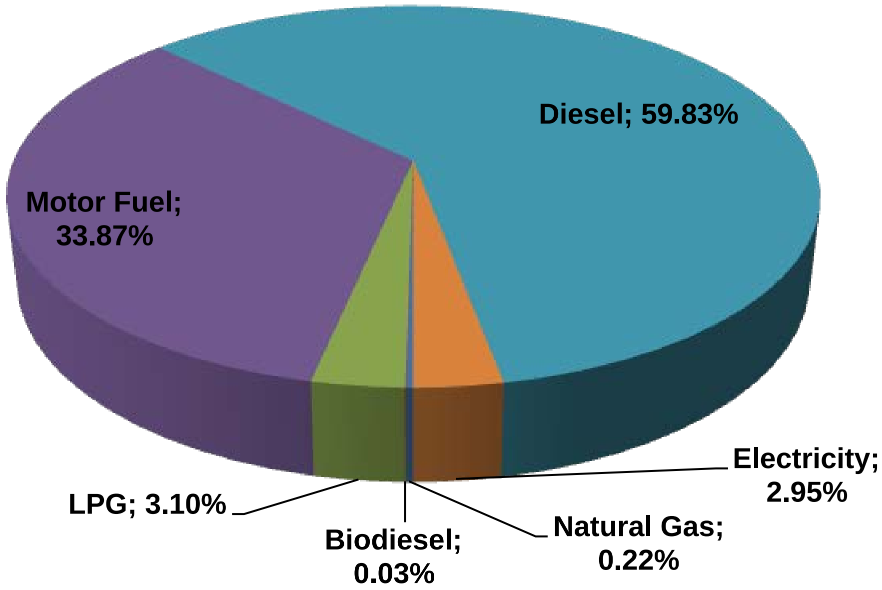



**Figure 13. Final energy consumption in transport in City of Zagreb in 2011 (by fuels)**

## *2.5 Biogas production and consumption in Croatia and City of Zagreb*

Croatian biogas market is an emerging market with nine operating plants (8.135 $MW_e$) and 53 pending projects (~80 $MW_e$) where agricultural feedstock is used as substrate. All biogas produced is aimed at CHP engines as, since 2007, RES-E FiT is the only incentive for energy from biogas. Since mid 2012, the new FiT mandates minimal overall efficiency of 50% for a biogas plant to be eligible for incentive purchasing price of electricity. So far, only one biogas plant has met the condition.

In mid-June 2013, there were 1 landfill biogas plant (extended from 2 to 3 MWel) and 1 waste water treatment biogas plant (2,5 MWel), both situated in the City of Zagreb. The landfill biogas plant is owned by Zagreb holding - Podružnica ZGOS, a subsidiary authorised to manage the City's landfill. The waste water treatment biogas plant is operated within the overall waste water treatment facility of the City of Zagreb, a concession contract run by consortium (WTE Wassertechnik GmbH (WTE) Essen, RWE Aqua GmbH (RWE Aqua) Mülheim and the City company Vodoprivreda Zagreb Inc).

The latter two landfill biogas plants are in planning phase, totalling with landfill and waste water treatment biogas project to 7,15 MWel.

The FiT for that category of biogas plant changed in 2012 and amounts to 0,53 kn/kWh, regardless of the size of the plant. No specific heat demand is required.

Related to the potential of developing biomethane from waste market and the WP4 Biogas and Biomethane Production in the City of Zagreb, four scenarios of biomethane production are being developed:

**Table 1. Biogas and biomethane production - Scenario 1 (mil.Nm$^3$/yr)**

| Parameter | Year | 2011 | 2015 | 2017 | 2020 |
|---|---|---|---|---|---|
| **Biogas production** | Mil.Nm$^3$/yr | 0.19 | 1.07 | 1.41 | 2.04 |
| **Methane production** | | 0.09 | 0.60 | 0.77 | 1.11 |

**Table 2. Biogas and biomethane production - Scenario 2 (mil.Nm$^3$/yr)**

| Parameter | 2011-base year | 2015 | 2017 | 2020 |
|---|---|---|---|---|
| **Biogas production** | 0.19 | 1.41 | 2.72 | 3.68 |
| **Methane production** | 0.09 | 0.85 | 1.63 | 2.21 |
| **Including IBW** | | | | |
| **Biogas production** | 0.19 | 3.85 | 5.22 | 6.24 |
| **Methane production** | 0.09 | 2.29 | 3.11 | 3.72 |

**Table 3. Biogas and biomethane production - Scenario 3 (mil.Nm$^3$/yr)**

| Parameter | 2011-base year | 2013 | 2015 | 2017 | 2020 |
|---|---|---|---|---|---|
| **Biogas production** | 0.19 | 1.84 | 2.63 | 2.99 | 3.41 |
| **Methane production** | 0.09 | 1.10 | 1.58 | 1.80 | 2.05 |
| **Including IBW** | | | | | |
| **Biogas production** | 0.19 | 1.84 | 5.07 | 5.50 | 5.98 |
| **Methane production** | 0.09 | 1.10 | 3.02 | 3.28 | 3.57 |

**Table 4. Biogas and biomethane production - Scenario 4 (mil.Nm$^3$/yr)**

| Parameter | 2011-base year | 2015 | 2017 | 2020 |
|---|---|---|---|---|
| **Biogas production** | 0.19 | 4.56 | 9.12 | 9.12 |
| **Methane production** | 0.09 | 2.73 | 5.47 | 5.47 |
| **Including IBW** | | | | |
| **Biogas production** | 0.19 | 7.00 | 11.62 | 11.62 |
| **Methane production** | 0.09 | 4.18 | 6.95 | 6.95 |

Biogas production, depending on the reference scenario for waste collection, will amount to between 1.1 and 6.95 million m$^3$ of biomethane in 2020. The minimum observed quantity of gas is about 4 times lower than the expected consumption of natural gas in ZET public transport. Calculated maximum volume of 6.95 million m$^3$ of biomethane represents only about 2 percent of the total final energy consumption of gas in the City of Zagreb. But it also should be noted that the above-mentioned potential production is 8 times higher than the consumption of natural gas in the area of Zagreb and possibly sufficient for 60 existing ZET buses.

In the following tables, possible hourly production of biogas/biomethane is estimated, based on 7,690 working hours of the upgrading plant.

**Table 5. Hourly biogas and biomethane production - Scenario 1 ($Nm^3/h$)**

| Parameter | 2011 | 2015 | 2017 | 2020 |
|---|---|---|---|---|
| **Biogas production** | 25 | 139 | 183 | 265 |
| **Methane production** | 11 | 79 | 100 | 145 |

**Table 6. Hourly biogas and biomethane production - Scenario 2 ($Nm^3/h$)**

| Parameter | 2011-base year | 2015 | 2017 | 2020 |
|---|---|---|---|---|
| **Biogas production** | 19 | 184 | 354 | 478 |
| **Methane production** | 11 | 110 | 212 | 287 |
| **Including IBW** | | | | |
| **Biogas production** | 19 | 501 | 679 | 811 |
| **Methane production** | 11 | 298 | 405 | 484 |

**Table 7. Hourly biogas and biomethane production - Scenario 3 ($Nm^3/h$)**

| Parameter | 2011-base year | 2013 | 2015 | 2017 | 2020 |
|---|---|---|---|---|---|
| **Biogas production** | 19 | 239 | 342 | 389 | 444 |
| **Methane production** | 11 | 143 | 205 | 234 | 266 |
| **Including IBW** | | | | | |
| **Biogas production** | 19 | 239 | 659 | 715 | 777 |
| **Methane production** | 11 | 143 | 393 | 426 | 464 |

**Table 8. Hourly biogas and biomethane production - Scenario 4 ($Nm^3/h$)**

| Parameter | 2011-base year | 2015 | 2017 | 2020 |
|---|---|---|---|---|
| **Biogas production** | 19 | 593 | 1,186 | 1,186 |
| **Methane production** | 11 | 356 | 711 | 711 |
| **Including IBW** | | | | |
| **Biogas production** | 19 | 910 | 1,511 | 1,519 |
| **Methane production** | 11 | 543 | 904 | 909 |

The production of biomethane from scenario 4 including the IBW would be sufficient for the fuelling of ZET bus fleet, but hourly biomethane production of maximum 909 $Nm^3/h$ is not sufficient (2700 $Nm^3/h$ is needed). Based on these results, we can conclude that the development of a fuelling station at the production site is technically unfeasible (insufficient capacity and fuelling infrastructure already exist at other location). The injection of biomethane in natural gas network is proposed.

# 3 Gas transmission and distribution

## 3.1 In Croatia (short)

Natural gas transportation is a regulated energy activity performed as a public service and represents the primary activity of the company Plinacro Ltd., which is the owner and operator of the gas transport system.

Company Plinacro Ltd. is a transmission system operator in the Republic of Croatia and it is owned by the Republic of Croatia. Plinacro Ltd. manages the network of main gas and regional gas pipelines through which natural gas from domestic production (northern part of continental Croatia and the north Adriatic) and from import (procurement transmission route via the Republic of Slovenia and Hungary is transmitted to exit measuring-reduction stations where the gas is delivered to gas distribution systems and to customers directly connected to the transmission system.

Today Plinacro operates 2511 km of high pressure gas pipelines, 1765 km of which are 50 bar system and 746 km of 75-bar system, 19 entry measuring stations, 154 exit measuring reduction stations with 257 measuring lines and a state-of-the-art National Dispatching Centre, i.e. communication system and centre of remote supervision and control of the gas transmission system. Plinacro controls its infrastructure through the National Dispatching Centre and four gas transmission regions – the Gas Transmission Region Eastern Croatia (with headquarters in Donji Miholjac), the Gas Transmission Region Central Croatia (with headquarters in Popovača), the Gas Transmission Region Northern Croatia (with headquarters in Zabok), the Gas Transmission Region Western Croatia (with headquarters in Rijeka), and the Maintenance Department and Storage located in Ivanić-Grad.

**Table 9. Diameters and lengths of transportation pipelines in Croatia**

| **DN (mm)** | 800 | 700 | 600 | 500 | 450 | 400 | 350 | 300 | 250 | 200 | 150 | <150 | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Length (km)** | 81 | 53 | 175 | 771 | 95 | 122 | 62 | 482 | 76 | 152 | 337 | 105 | **2511** |

**Table 10. Diameters and lengths of transportation pipelines in Croatia**

| **Transportation gas pipelines** | International | Main transmission lines | Regional | Local linking lines | **Total** |
|---|---|---|---|---|---|
| **Length (km)** | 37 | 1516 | 647 | 311 | **2511** |


**Figure 14. Transport system of natural gas in the Republic of Croatia**

In 2011, 3.309 billion cubic meters of natural gas were transported, of which 2.99 billion cubic meters from the entry to exit measuring-reduction stations, and 319 million cubic meters to the underground storage Okoli. At the system level, maximum transport of 13 581 207 cubic meters per day was achieved in 2011.

Gas was delivered to the transmission system through ten entry measuring stations. Out of these ten, eight stations are taking gas from domestic gas fields while two stations have international character as they are entry stations for imported gas (from Russia, Slovenia, Italy, Hungary).

The whole natural gas transport system transmits gas to 16 Counties.

In late 2010 Croatia gained a second supply source of natural gas, by completing the construction of the interconnection pipeline between Croatia and Hungary of 6.5 billion $m^3$ capacity of gas per year. This will free up capacity on the existing import route across Slovenia and Austria to enable the importation of additional quantities of gas from the largest gas trading centre in Central and South-eastern Europe - Austria's Baumgarten.

Gas distribution is a regulated energy activity performed as a public service. In 2011, gas distribution in the Republic of Croatia was performed by 36 companies. Most of them obtained licence for the period of 5 years, and only nine of them for a 15-year period.

According to the data collected from 36 distribution system operators, the total distributed quantities of gas in the Republic of Croatia in 2011 amounted to 1.237 M $m^3$ which is by 6% less than the quantities of gas distributed in 2010. Out of the total quantity of gas distributed, 712 M $m^3$ (58%) was distributed to users of the household tariff group and 525 M $m^3$ (42%) to users of the commercial tariff group. In 2011 the total number of distribution system users amounted to 643.618, out of which 589.817 were users of the household tariff group and 53.801 of the commercial tariff group. Out of the total number of commercial tariff group in 2011, 68 users realized annual natural gas consumption above 1M $m^3$ and under or equal to 5M $m^3$ and 4 users realized an annual consumption of the natural gas above 5M $m^3$.

The next graph presents all registered natural gas distribution companies in Croatia, their gas consumption and market shares in 2011.

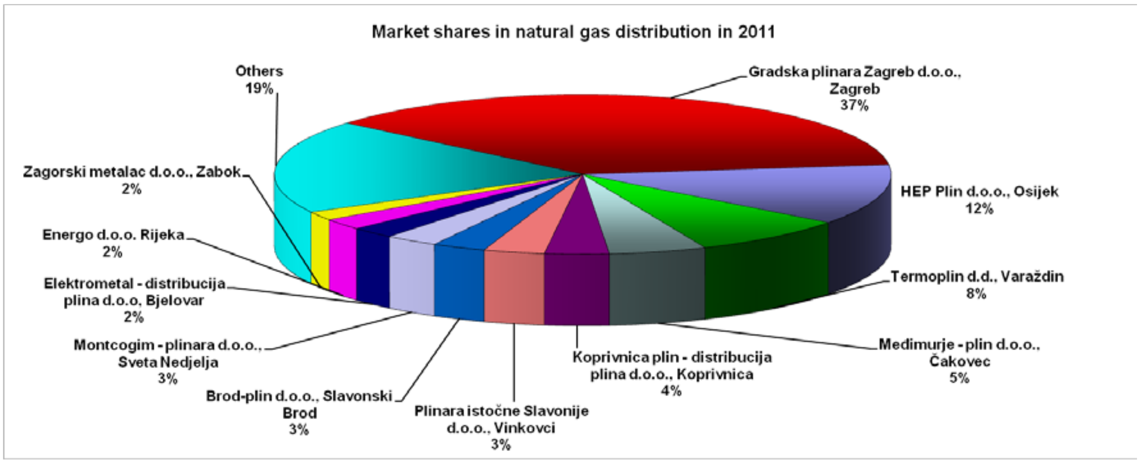



**Figure 15. Market shares in natural gas distribution in Croatia in 2011**

The total length of the gas distribution network in the Republic of Croatia at the end of 2011 amounted to 18.149 km, which is 0.8% more compared to the total length of all gas distribution network at the end of 2010. The total number of odorisation stations in all distribution systems at the end of 2011 amounted to 119.

**Table 11. Distribution pipeline length in Croatia**

| Distribution gas pipelines | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Length (km) | 12.220 | 13.340 | 14.366 | 14.366 | 14.515 | 14.984 | 15.531 | 16.219 | 16.541 | 17.184 | 17.581 | 17.666 | 17.920 | 18.149 |


**Figure 16. Distribution areas of the distribution systems in the Republic of Croatia in 2011**

Basic gas price elements include natural gas wholesale supply price, transmission tariff, storage tariff, distribution tariff and retail supply price. Transmission, distribution and supply of protected customers are regulated by the tariff systems defined by the Croatian Energy Regulatory Agency (CERA).

The gas transmission price is defined by the Tariff system for natural gas transmission, without the amounts of tariff items (Official Gazette 134/11, 2/12).

Tariff items for storage of natural gas are set by the gas storage tariff (Official Gazette 151/08, 13/09, 2/11).

The Decision on tariff items in the Tariff system for natural gas distribution, without tariff items (Official Gazette 34/07, 47/07, 44/10, 13/12), which determines the amounts of the individual tariff items for the costumers connected to the distribution system.

### 3.2 In City of Zagreb

Back in 1862 a contract was signed on building a factory to produce gas for city lighting. The first factory used the process of dry distillation of wood, and it was located on what was then the edge of the city on the corner of Gundulićeva and Hebrangova Street (today's HEP building). On 31 October 1863, the first plant began work enabling Zagreb's streets and squares to be lit by 364 gas lamps. The City Council rendered a decision in 1898 to buy off the gasworks, so it became Zagreb City Gasworks. In December 1955 natural gas arrived in Zagreb and from 1971 work has been going on to exchange city gas for natural gas. In August 1978 the western gas line was built to import natural gas.

Distribution of natural gas in the City of Zagreb is performed by the energy company Zagreb City Gasworks Ltd., which is wholly owned by Zagreb Holding Ltd. As the operator of the distribution system it provides the technical conditions to power, manage and develop a safe, reliable and efficient distribution system and supervise design, construction and maintenance of the distribution system. Moreover, Zagreb City Gasworks manages the cadastre of lines, undertakes technical tests and analysis and examines and regulates pressure gauges. It also takes care of strategic investment in building gas supply facilities for »large scale consumers« and creates project documentation and offers services of professional supervision of construction.

Today, City Gasworks distributes natural gas in the area of the City of Zagreb, the towns of Zaprešić and Velika Gorica and the municipalities Pušća, Dubravica, Marija Gorica and Brdovec.

Total length of gas pipelines controlled by City Gasworks is 5206 km, where City of Zagreb holds the biggest share of 79.3%. Velika Gorica holds 6.3% of the "pie", Zaprešić 5.9%, Brdovec 4.9%, Pušća 1,9%, Marija Gorica 1,5% and Dubravica 0,9%.

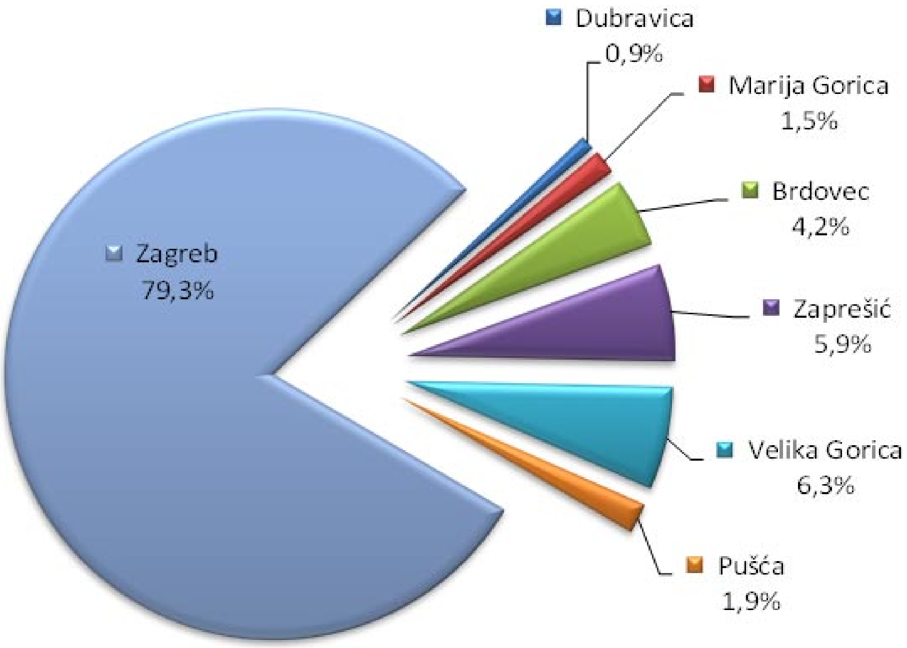



**Figure 17. Distribution network length by city of Zagreb City Gasworks**

From the year 1971 to 2011 gas network, with some fluctuations, was rather uniformly increasing to 1997, and between 1998 and 2004 it spread rapidly (about 200 000 m per year, with a record of 356 000 m in 1999). A period of stabilization has followed since 2005, during which the annual increase was slightly more than 100 000 m. In 2009 the increase dropped to 43 000 m, and then stabilized between 25 000 and 30 000 m per year. At the end of 2011, the total network length of Zagreb City Gasworks reached 3 691 000 m.

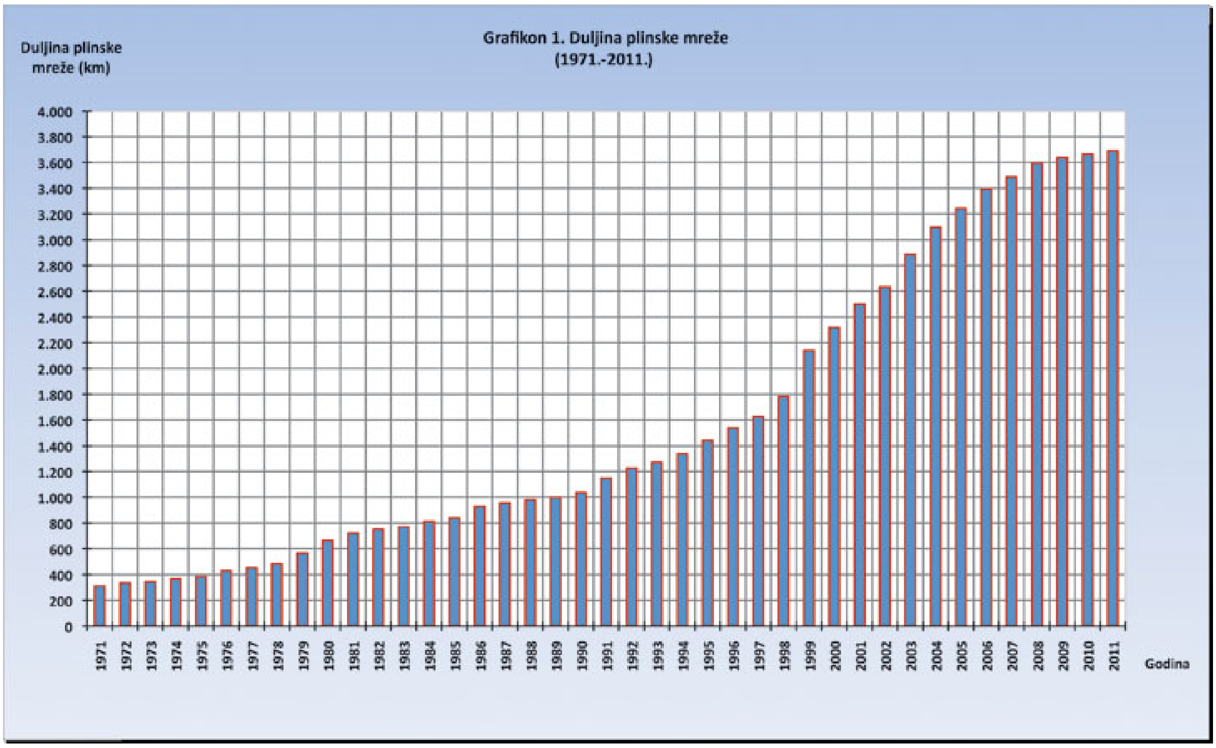



**Figure 18. Length of the distribution network through history (Zagreb City Gasworks)**

The following map shows the spread of the gas network through history. It can be seen that the urban areas and industrial zones were gasified in 1982 (see map - dark blue). Until then, the total length of the network was 762 000 m with the total of 34 945 consumers. Between 1983 and 1992 the network has been extended to 1 207 000 m, and the total number of consumers stood at 110 264 (see map - yellow). What followed was a decade during which the total length of the network was more than doubled, and in 2002 it amounted to 2 633 000 m, and there were 172,617 consumers connected (see map - green). By the end of 2011, the network increased to 3 691 000 m with 271 438 consumers (see map - purple).

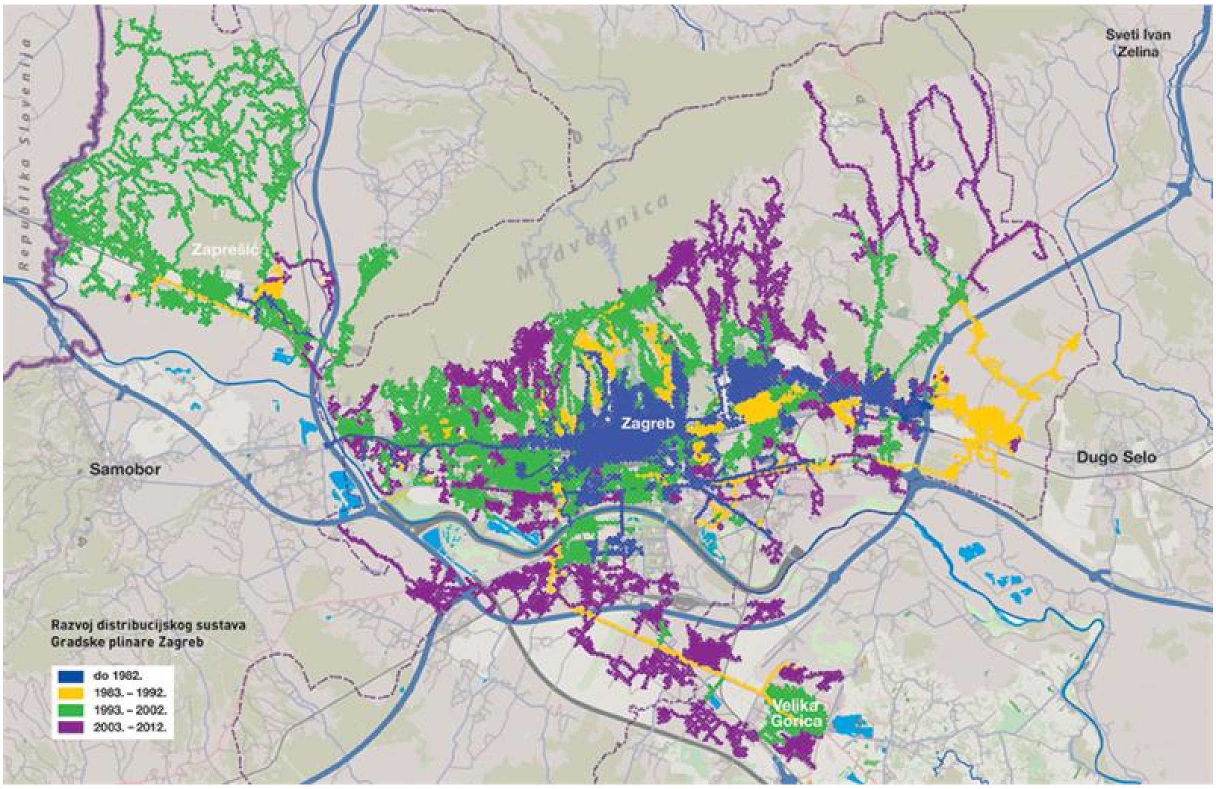



**Figure 19. Development of the distribution system of Zagreb City Gasworks**

The operating pressures of gas systems are:

- high pressure: 6 bar
- middle pressure: 3 bar
- low pressure: 100 mbar

Through history, regarding gas delivery, City of Zagreb was initially supplied with only about 400 000 m³ gas per year and the consumption was constantly growing until 1915. Recovery from the consequences of the First World War lasted until 1926. Again, constant growth followed until the end of World War II. After World War II, production has fallen in value, and was the same as in 1915, but before the end of the ‘40s it again reached and exceeded the interwar maximum. After stagnation in the '50s, the '60s gas supply has grown rapidly and in 1971 amounted to 136 million m³. Over the next decade, the supply has tripled, and then again stagnated. Since 1986 the annual delivery of gas has constantly risen and in 1993 reached the absolute maximum gas supply in the history of gasworks: 655 453 000 m³. Due to separation of the large plants (CHP) from the gasworks distribution system, reduction of gas distribution soon followed.

Amount of natural gas distributed on the territory of the City of Zagreb in 2011 totalled 451.619 Mcm. The largest share of gas distributed is used in households, and then in industry, service sector and in heating plants.

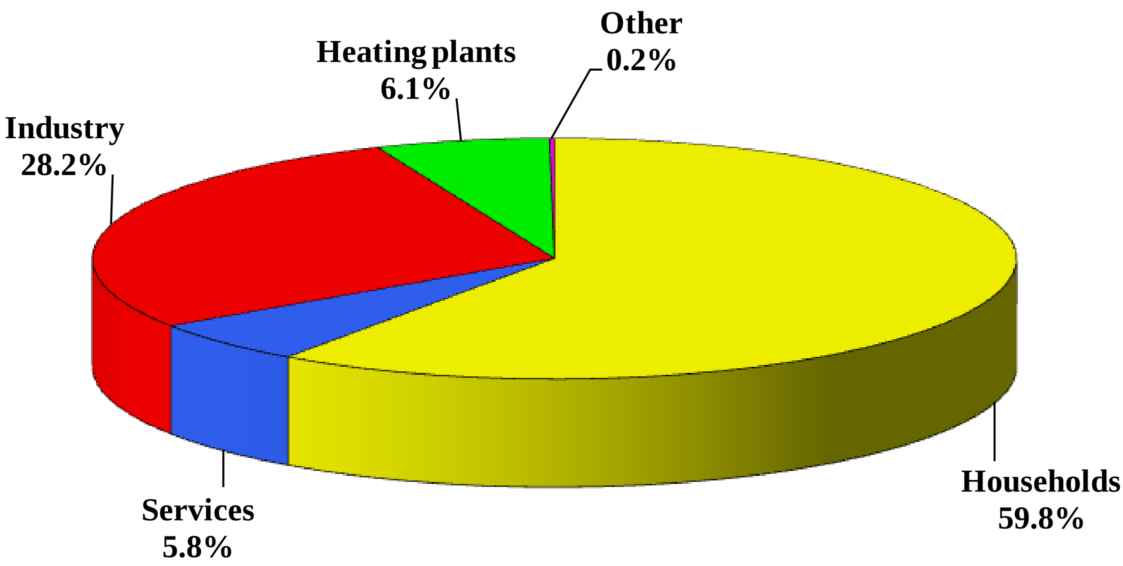



**Figure 20. Natural gas distribution in the City of Zagreb in 2011 (shares)**

The number of consumers was also increasing similarly; a fairly uniform rise until 1997, when their number reached 129 528. Since 1998 there has been a steady rapid growth in the number of consumers. At the end of 2011 there were 271,438 Zagreb City Gasworks consumers. Most of them were households.

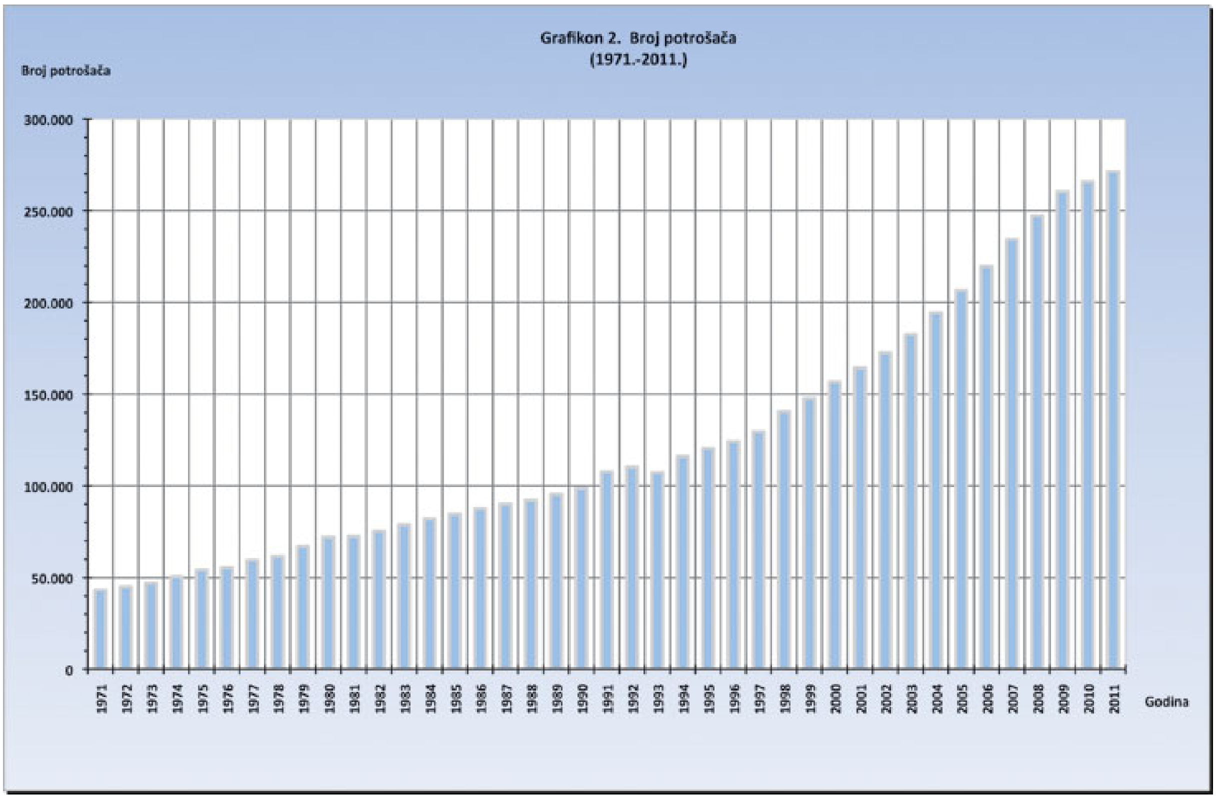



**Figure 21. Number of Zagreb City Gasworks consumers through history**

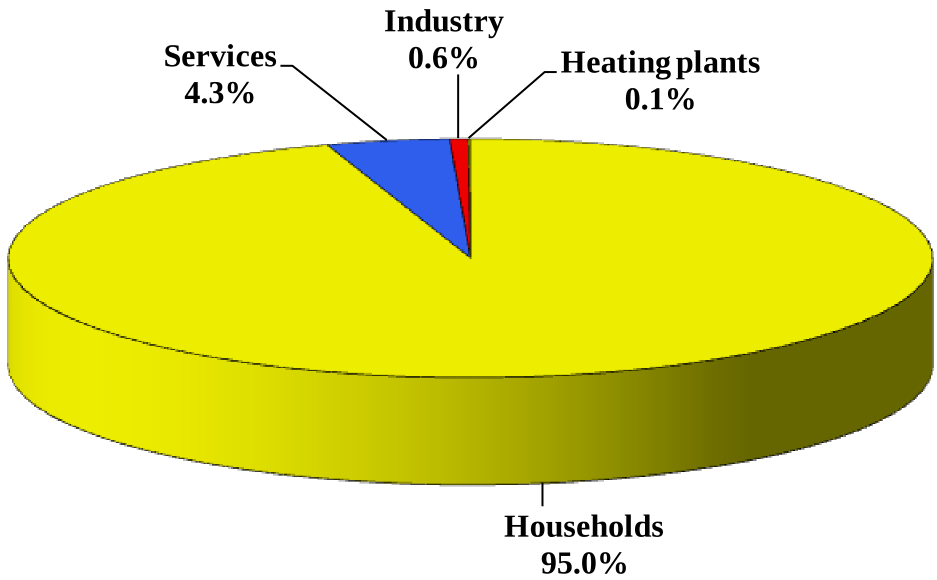



**Figure 22. Natural gas consumers in the City of Zagreb in 2011**

The major retail supplier in the City of Zagreb is Zagreb City Gasworks – Supplies company. The company was founded on 24 April 2008 by Zagreb City Gasworks on the basis of provisions of the Gas Market Act (OG 40/07) and Directive 2003/55 of the EC, which prescribes the obligation of separating the work of gas supply from distribution of gas as a basic condition for liberalizing the natural gas market in the Republic of Croatia and alignment with the acquis of the EU. With respect to the guidelines of the Gas Market Act, by a Contract on Transfer of business shares, dated 24 November 2008, Zagreb Holding became the owner of Zagreb City Gasworks. On 8 May 2009, a Permit for Performing the Work of Supplying Gas was awarded by Croatian Energy Regulatory Agency (HERA).

Calculation and payment of natural gas by consumers on the gas distribution system, sales of compressed natural gas (CNG) for motorized vehicles, and calibration of gas meters and pressure gauges are the basic activities of this commercial company.

In Zagreb, near Zagreb City Gasworks, there is one of the three operating CNG filling stations in Croatia (Radnička cesta 1), which delivered to its customers through 15,000 filling operations the total of 1,251,123 $m^3$ of natural gas in 2009. In addition, ZET currently uses 60 buses on CNG which can use compressed biomethane (CBM). Thus it can be concluded that there is experiencs for establishing the distribution and use of CBM.

For illustration, the technical characteristics of this filling station are shown in the table below.

Filling station was built late in 1994 and put into operation in March 1995.

Figure 23. CNG filling station in the City of Zagreb (Radnička cesta 1)

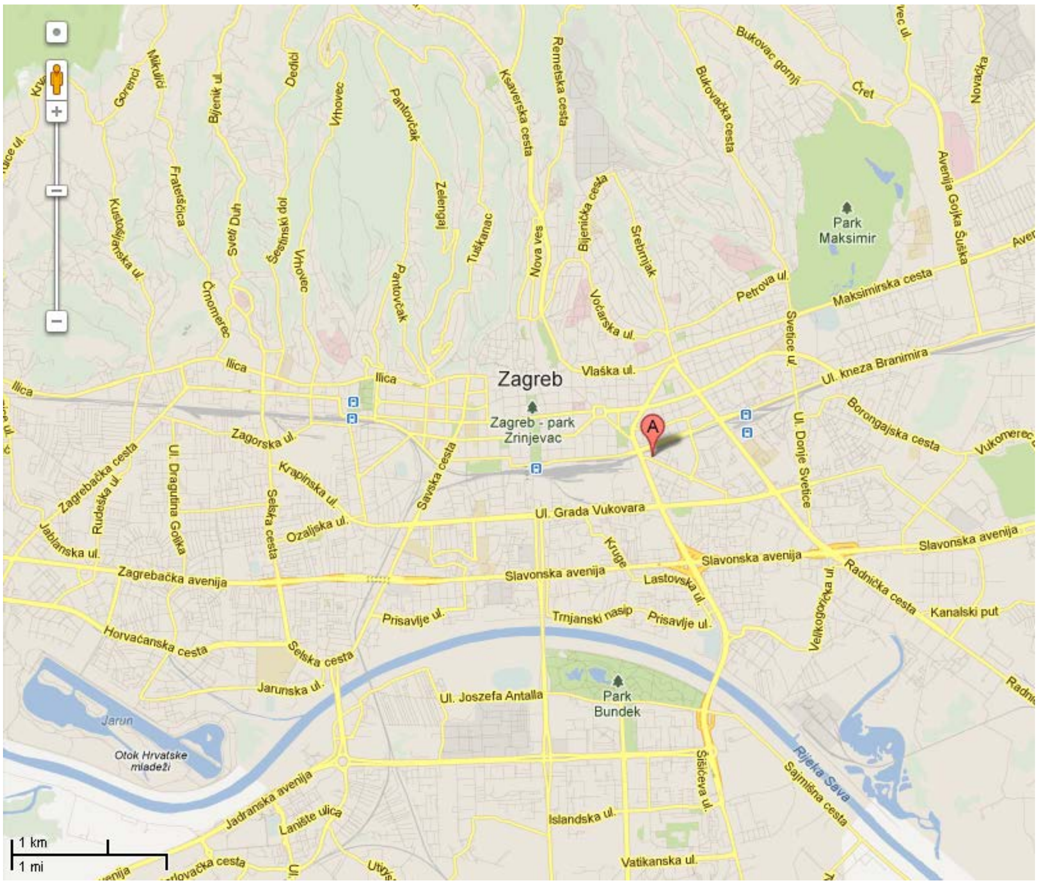



Figure 24. Location of the CNG filling station – Radnička cesta 1 (1)

**Figure 25. Location of the CNG filling station – Radnička cesta 1 (2)**

**Table 12. Characteristics of existing compressed natural gas filling stations for motor vehicles (Zagreb City Gasworks - Radnička cesta 1)**

| | |
|---|---|
| Construction year | *1994/5* |
| Location | *Zagreb, Radnička cesta 1* |
| Operation | *Two gas engines of 119 KW* |
| Compressor | *Two 4-stage compressors with a radial piston (the pattern of "star")* |
| Compressor capacity | *330 $m^3$/h* |
| Maximum operating pressure / working pressure | *250/220 bar* |
| Gas tank | *Volume 1,2 $m^3$ in 14 cylinders (4 with high pressure and 10 with medium pressure)* |
| Number of chargers | *2 (possible upgrade to 3)* |
| Filling capacity | *0,3 – 16 kg/min* |
| Filling station capacity | *200 - 400 vehicles/day* |

**Figure 26. Details of existing CNG filling station (location: Radnička cesta 1)**

## Gas prices

With the decision of the Government on the tariffs in Tariff System for Natural Gas (**OG 49/2012**), the price of natural gas for customers in the category "Household" is expressed in kn/kwh. The price of natural gas with standard calorific value in tariff $Ts_1$ is 0,39008875 kn/kwh. Price for gas supply to gas wholesale suppliers is determined with the amount 0,237563 kn/kwh by Government (from 1 May.2012). With the decision by the Government of Croatia on the tariffs for transport of natural gas, the price for transmission from 1September.2009 is 0,02730600 kn/kwh. With the decision by the Government of Croatia on the tariffs for natural gas distribution, the price for distribution of natural gas from 1 May2012 is 0,038874 kn/kwh. Value Added Tax (VAT) in Croatia is 25%.

A fixed fee for natural gas distribution was introduced with the decision of the Government of Republic of Croatia on 27 April 2012 (OG 49/2012). The amount of 16,50 kn + VAT is charged monthly per name account and for the account of the distribution system by natural gas suppliers.

**Table 13. Natural gas price for households**

| TOTAL COST OF NATURAL GAS - COMPONENTS (HOUSEHOLDS) | | | |
|---|---|---|---|
| **Authority** | **Activity** | **Price (kn/kwh)** | |
| Prirodni plin d.o.o. Zagreb | wholesale supply | 0,237563 | 61% |
| Plinacro d.o.o. | transmission | 0,02730600 | 7% |
| Gradska plinara Zagreb d.o.o. | distribution | 0,03887400 | 10% |
| Gradska plinara Zagreb - Opskrba d.o.o. | retail supply | 0,00832800 | 2% |
| Republic of Croatia | Value- Added Tax | 0,07801775 | 20% |
| **Total** | | **0,39008875** | **100%** |

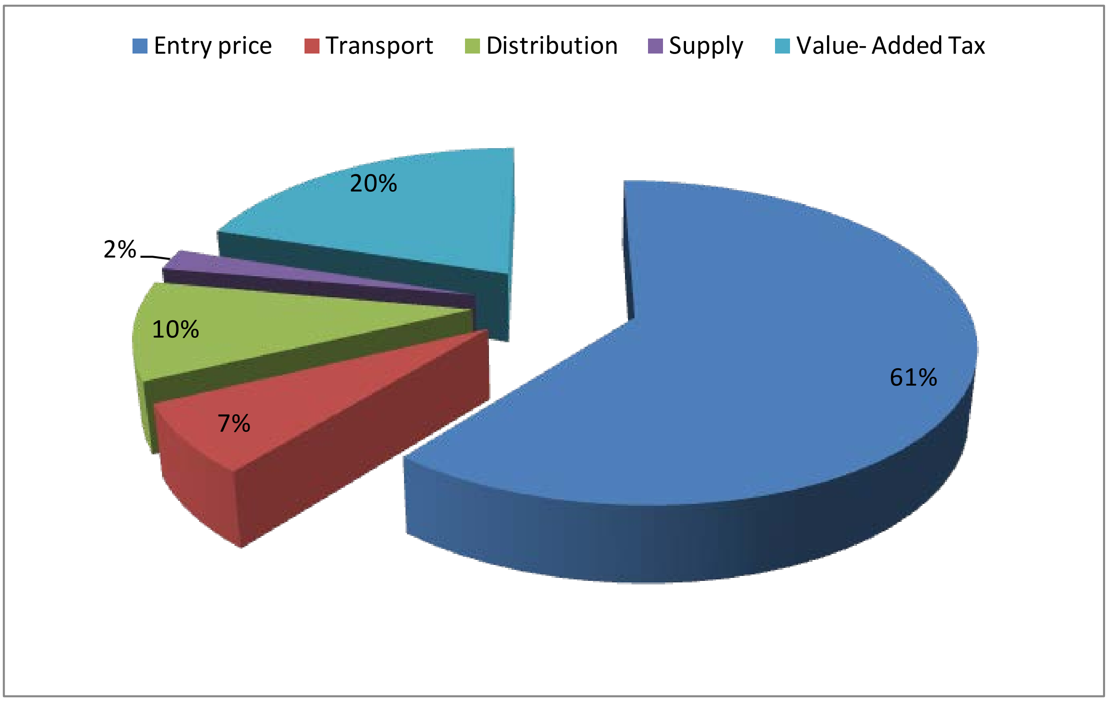



**Figure 27. Components of natural gas price for households**

The price of 1 kwh of natural gas to commercial customers is formed on the basis of:

- Government decision on tariffs in the tariff system for distribution of natural gas, without tariff item (NN 49/2012).
- Government decision on tariffs for transportation of natural gas from 2009 (NN 103/2009).
- Natural gas prices, calculated by suppliers of natural gas in accordance with the formulas from the Agreement on the sale of natural gas in the gas year 2012/13.
- Gas supply contracts between the supplier and the end customer, in accordance with the General conditions of gas supply (NN 43/09) – Art. 28.

In accordance with the Government decision on tariffs in the tariff system for distribution of natural gas, without tariff item (NN 49/2012), there are three tariffs for commercial customers (TM2, TM3 and TM4). Gas distribution prices for TM2 (Total annual consumption of natural gas is less than or equal to 10 GWh) are 0,025916 kn/kwh (Ts1) and 16,50 for fixed fee for natural gas distribution (Ts2). Gas distribution prices for TM3 (Total annual consumption of natural gas is higher than 10 GWh and less than or equal to 50 GWh) are 0,019437 kn/kwh (Ts1) and 60 for fixed fee for natural gas distribution (Ts2). Gas distribution prices for TM4 (Total annual consumption of natural gas is higher than 50 GWh) are 0,008639 kn/kwh (Ts1) and 60 for fixed fee for natural gas distribution (Ts2). Since the supply price for commercial customers is unpublished and market driven (supply price is bigger than households protected price), we can calculate that it should be around 0,5 kn/kWh , VAT included.

Price of CNG supplied by City Gasworks Zagreb – Supply Ltd. is 6 kn/kg plus VAT (7.5 kn/kg or 0.56 kn/kWh including VAT).

# 4 Public transport in City of Zagreb

Public transportation in the City of Zagreb is organised through bus and tram traffic, and a funicular as a tourist attraction which connects the Upper and the Lower Town. Besides that, public transportation is also organised through taxi vehicles, but with a very small share in passenger transportation in relation to the bus and tram traffic.

Zagreb Electric Tram (ZET) is the only concessionaire entrusted with providing the service of public transportation of passengers in the administrative territory of the City of Zagreb as well as in part of the territory of Zagreb County. Tram and bus transportation are mutually very well integrated, they use a common system of tickets and together they make a unique system of public transportation.

Buses do not operate in the central part of the City, but a connection to the tram network through numerous terminals which are located on the border parts of the central part are organised. In 2008, public transportation on the territory of the City of Zagreb transported the total of 298 603 000 passengers.

The share of tram and bus transportation in total number of transported passengers is presented in the figure below.

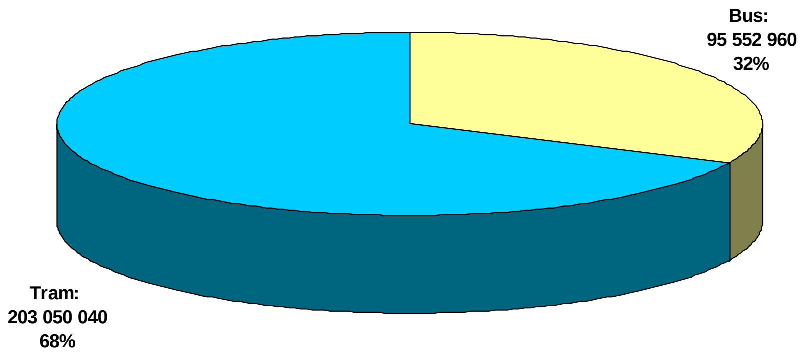



**Figure 28. Individual transportation share in the total number of transported passengers in Zagreb in 2008**

Tram network is the skeleton of public transportation. Regular tram transportation takes place on 116.346 m of tracks (approximately 58 km in each direction), on which 191 motor tram vehicles and 62 trailers run every day. Total length of tracks on 15 lines of day traffic is 148 km, and on four night lines 57 km. There are two main change points, Ban Josip Jelačić square and the Central station. There are 167 switches in the town, and 256 tram stops. Approximately 204 million passengers are transported annually in trams in the City of Zagreb.

Public bus transportation in the City of Zagreb is organised on the territory of the City of Zagreb and on the territory of certain neighbouring cities and municipalities. The expansion of the bus network is limited by the network of main roads and the topology of the town, and for that reason it has a relatively small density of coverage. The entire bus traffic is organised in 130 daily and 4 night lines.

ZET's bus network includes 2103 bus stops, 1614 of which are located on the territory of the City of Zagreb itself. The lines are run from the bus terminals located on the edge of the central area to which trams arrive towards the border parts of the town.

On working days, 279 buses operate on the regular lines, 186 buses on Saturdays, and 120 buses on Sundays and holidays. Since 2007, ZET has also been organising the transportation of pupils on the territory of the City of Zagreb. Approximately 94 million passengers are transported annually in ZET's buses.

The bus transport fleet, which in 2008 consisted of 328 vehicles, includes MAN and Mercedes-Benz vehicles. Buses are located in three garages: Podsused, Dubrava and Velika Gorica. The buses are mostly low-floor and for that reason accessible by different categories of the population. Twenty buses have been running on biodiesel on the territory of the City since 2007. After a study on the justifiability of the use of natural gas in public transportation vehicles was done in 2006, ZET has begun the acquisition of vehicles which run on compressed natural gas.

ZET has three bus terminals, namely garages at locations: Dubrava, Podsused and Velika Gorica. There are 130 buses at Dubrava location, 150 at Podsused location and the total of 30 buses at Velika Gorica.

An analysis of existing bus lines was conducted and lines where it is expected that the use of gas would express its full economic, environmental and advertising efficiency were defined.

When selecting candidate lines, the following criteria were used:

- The upper limit of the daily travelled distance is approximately 300-330 km (in order to optimize the required number of compressed natural gas containers, meaning to optimize a specific investment by bus)
- The advantage is, where possible, given to the lines that operate in those parts of town where the promotional impact is greater.
- The advantage is, where possible, given to the so-called strong lines (higher occupancy, provided that they meet the criterion of maximum daily travelled distance)
- Mountain lines are omitted from the first phase (that is, given that gas engines use Otto-cycle their torque should be slightly lower compared to diesel engines, and thus somewhat less powerful when it comes to driving up the hill, which is partly due to additional weight of the bus because of the weight of compressed natural gas tank. Bus manufacturers (for example, Iveco) report that their models of buses powered by compressed natural gas are able to meet the requirements related to the mountain lines in a completely same way as models driven by a diesel engine, but the use of buses powered by compressed natural gas in mountain lines is left for the second phase (after experience is gained in the first phase).
- Advantage, where possible, have buses that come into the garage early in the evening, or set off from the garage later in the morning.
- The advantage is, where possible, given to the lines operating within urban centers (with a higher density of population and traffic) due to a planned use of buses with extremely low harmful gas emissions (EEV class - Environmentally Enhanced Vehicle) whose positive effect in these areas is higher compared to peripheral (suburban) lines.

Based on the above criteria, about 25 lines were selected as potentially attractive for the switch to compressed natural gas, which powers a total of about 90 buses. Total annual consumption of natural gas per bus would amount to approximately 62 000 m3 per year.

Based on the above mentioned results, the total of sixty buses run by natural gas was purchased in 2009 (40 joint and 20 classic) in the first phase.

ZET has received funds from European funds (*Civitas Elan Programmes*) for the construction of infrastructure for natural gas vehicles usage: for construction of a compressed natural gas filling plant, reconstruction of maintenance garages for the maintenance of buses running on gas, and installation of gas alarm system in natural gas powered buses related to infrastructure.

# 5 Technical requirements for biogas use

## 5.1 Grid injection

There are several options for grid injection in the city of Zagreb.

The first and most expensive option is an injection into the gas transmision network (50 bar). The cost of compressing biomethane to this level may be uneconomical.

High pressure distribution pipelines (6 bar) present an interesting injection point since pressure is similar to some biogas upgrading processes. Furthermore, the volume of natural gas is significant to guarantee significant consumption volume even during summer months.

Injection into the middle pressure distribution network (3 bar) or low pressure distribution network (100 mbar) is the final and possibly most practical solution. However, the area covered with medium or low pressure gas network should be large enough to ensure that the minimal summer load is greater than biomethane project flow.

Injection and monitoring schemes, depending on the size of biomethane production and security requirements, can vary from simple injection systems up to more complex injection system. A simple injection system might be used for the injection of biomethane to the gas distribution network.

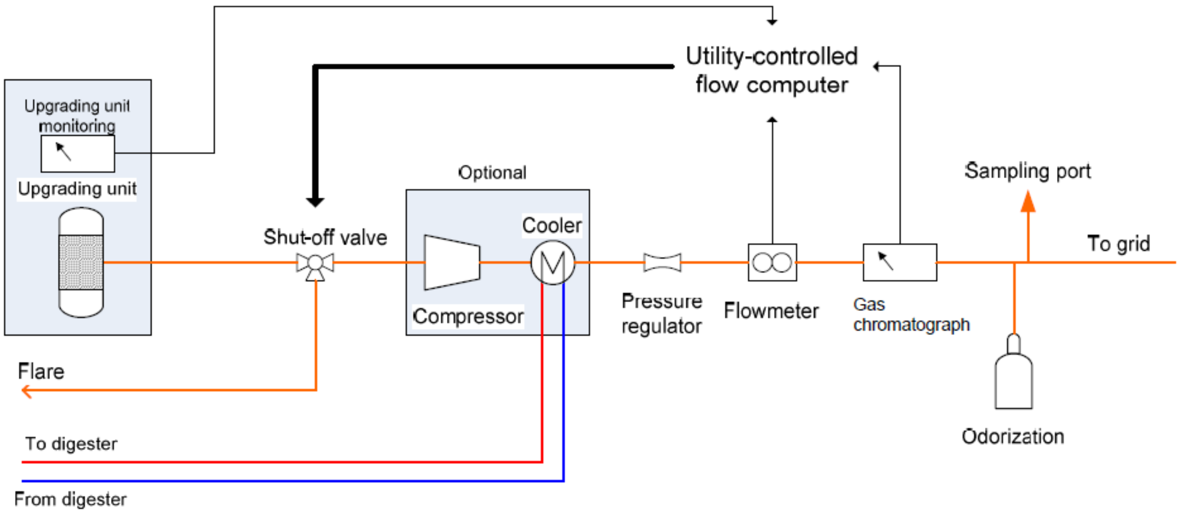



**Figure 29. Simple biomethane injection and monitoring system**

*Source: (Feasibility Study – Biogas upgrading and grid injection in the Fraser Valley, British Columbia)*

A simple monitoring system (shown above) comprises several components and costs 120 000 - 160 000 EUR (without compressors).

- A three-way flow valve that can be closed by the plant or the utility if biomethane does not meet the quality requirements. Biomethane would then be recirculated to the upgrading unit, flared or recycled into the boiler;
- A compressor (a cooler/dewatering unit can be added if higher pressure is needed),
- A pressure regulator to keep the pressure at the level needed for injection,
- A flow meter for billing purposes,
- A gas chromatograph to measure and secure acquired gas composition and to indicate gas heating value,
- A flow computer to be operated by the utility, allowing it to shut the valve off if gas quality becomes off-specification. This computer would also record production rates and enable the utility to bring the injection process back to operation by re-opening the three-way valve,

- A downstream odorizing unit, and
- A sampling port for discrete sampling.

A more complex injection system might be used for the injection of biomethane to the gas transmission network.

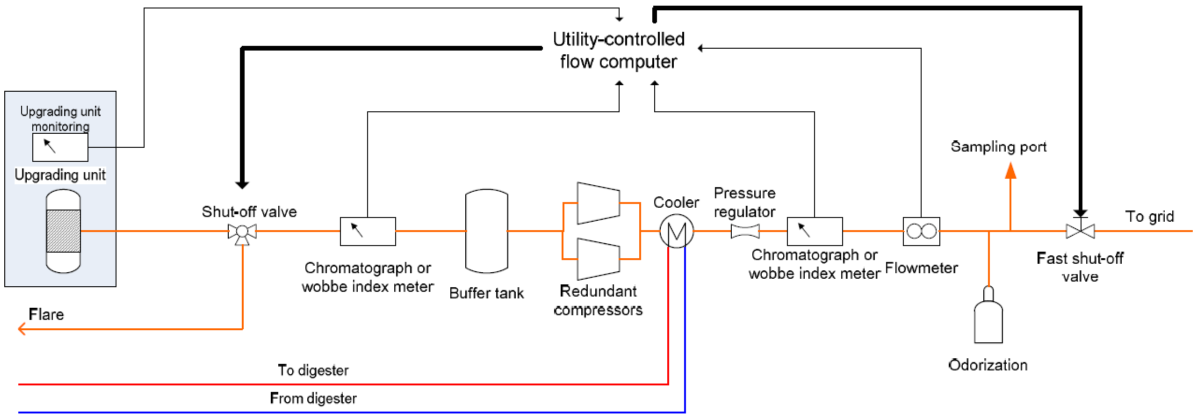



**Figure 30. Complex injection and monitoring system**

*Source: (Feasibility Study – Biogas upgrading and grid injection in the Fraser Valley, British Columbia)*

A more complex injection and monitoring scheme (similar to the one above) would cost 120 000 – 300 000 EUR and might be comprised of additional technology. These include:

- additional chromatograph and/or Wobbe index meters to replace the specific gravity meter. This would measure heating value, CH4, CO2, O2, H2S and dew point every three minutes.
- A buffer tank for gas to sit before a reading is made by gas quality equipment (so fast shut-off valve can be closed before any off-spec gas is injected into the grid), and
- A second compressor to ensure that the plant keeps running when maintenance

  is performed on the main compressor.

Monitoring the quality and quantity of biomethane has to be done by the plant operator. The utility may use the same meters or add its own at the delivery point. The utility may also use remote monitoring as well as human performed readings on data logging equipment.

Based on the available biomethane production rates, that in most optimistic scenarios won't exceed 1000 m3/h, the connection to distribution network should be envisaged.

Depending on the upgrading technology, additional compression might be needed. The upgrading technology and pressure from upgrading unit:

- Amine Wash (COOAB) - 150 mbar
- PSA – 4-7 bar
- Water scrubber – 5-10 bar

With water scrubber technology we can enter high pressure distribution network without a compressor (reduction of pressure is needed), with PSA technology the medium pressure network might be entered and with amine wash low preasure network might be entered.

The WP4 Biogas and Biomethane Production in the City of Zagreb analysed following sites that are considered as parts of Overall Waste Management Plan for City of Zagreb as possible biogas production sites due to the following reasons:

1. **Prudinec** - existing landfilling site:

Regarding access to natural gas distribution grid; closest distance from the medium pressure network (4 bar, 225 mm) is 4 324 m and from the high pressure network (6 bar) is 5 215 m. Distance from the nearest transport gas pipeline connection is 8 407 m (MRS Zg Jug, 50 bar, 500 mm). Distance from the nearest ZET garage (planned CNG filling station) is 10 428 m (Dubrava).

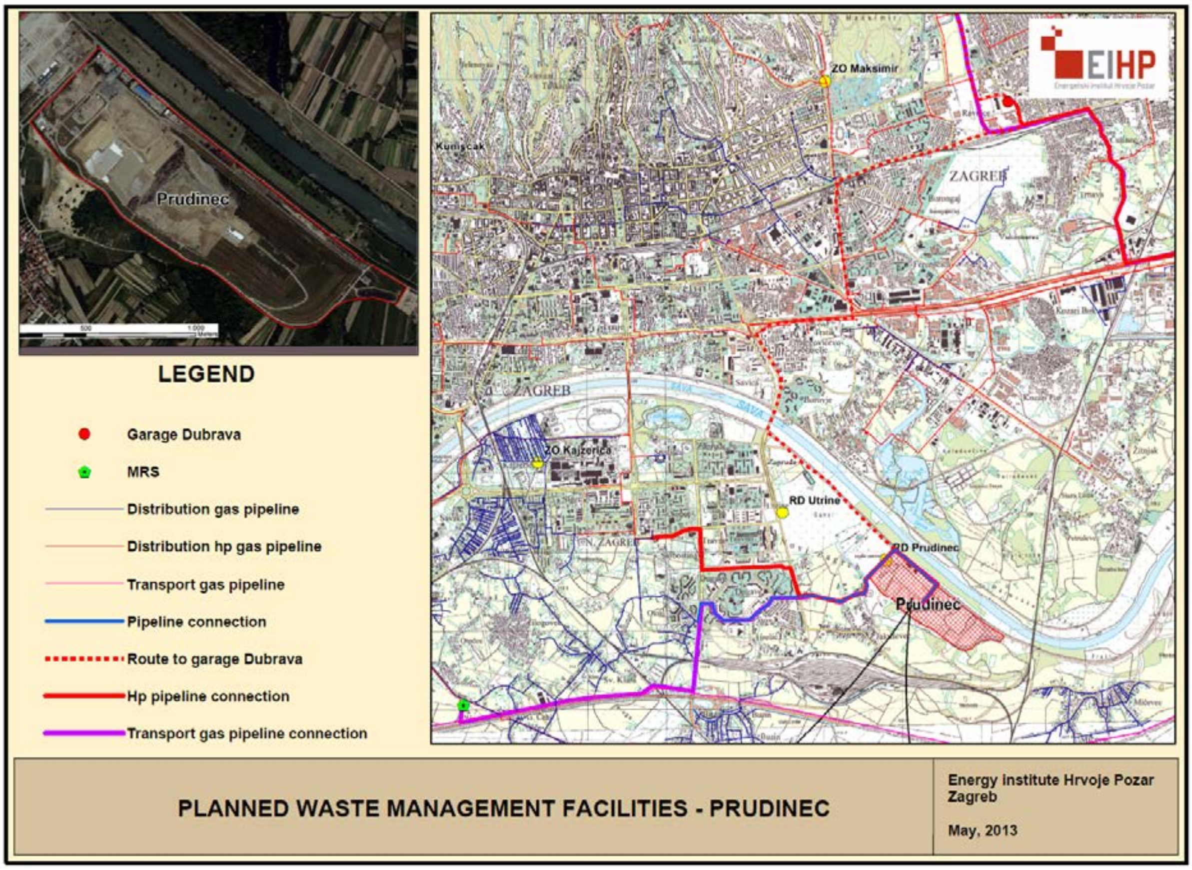



**Figure 31. Planned waste management facility - Prudinec**

1. **Resnik** - location next to the existing Central WWTF:

Regarding access to natural gas distribution grid; closest distance from the medium pressure network (4 bar, 160 mm) is 457 m and from the high pressure network (6 bar) is 779 m. Distance from the nearest transport gas pipeline connection is 1 848 m (MRS Zg East, 50 bar, 250-300 mm). Distance from the nearest ZET garage (planned CNG filling station) is 6666 m (Dubrava).

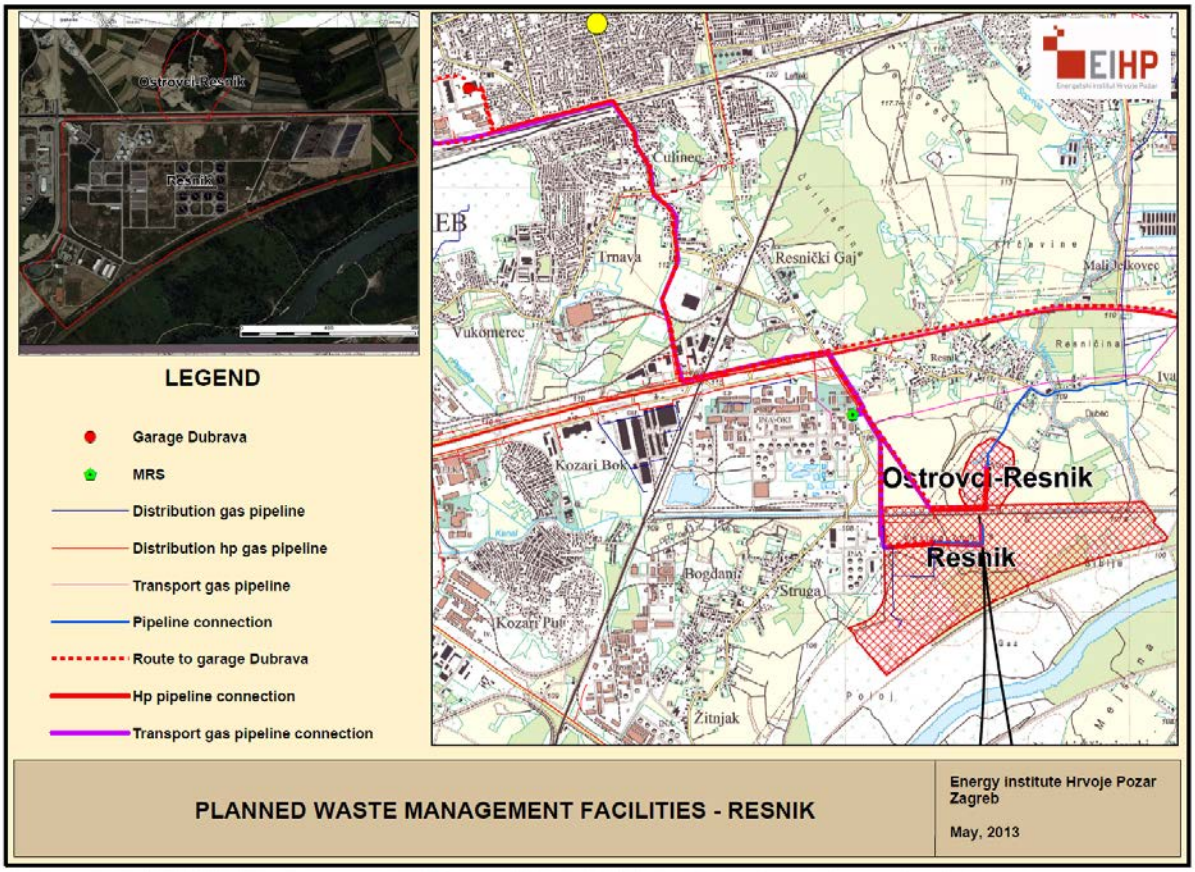



**Figure 32. Planned waste management facility – Resnik, Ostrovci - Resnik**

1. **Markuševec** - existing composting site for biodegradable waste

Regarding access to natural gas distribution grid; closest distance from the medium pressure network (4 bar, 225 mm) is 365 m and from the high pressure network (6 bar) is 837 m. Distance from the nearest transport gas pipeline connection is 8 254 m (MRS Zg East, 50 bar, 250-300 mm). Distance from the nearest ZET garage (planned CNG filling station) is 3270 m (Dubrava).

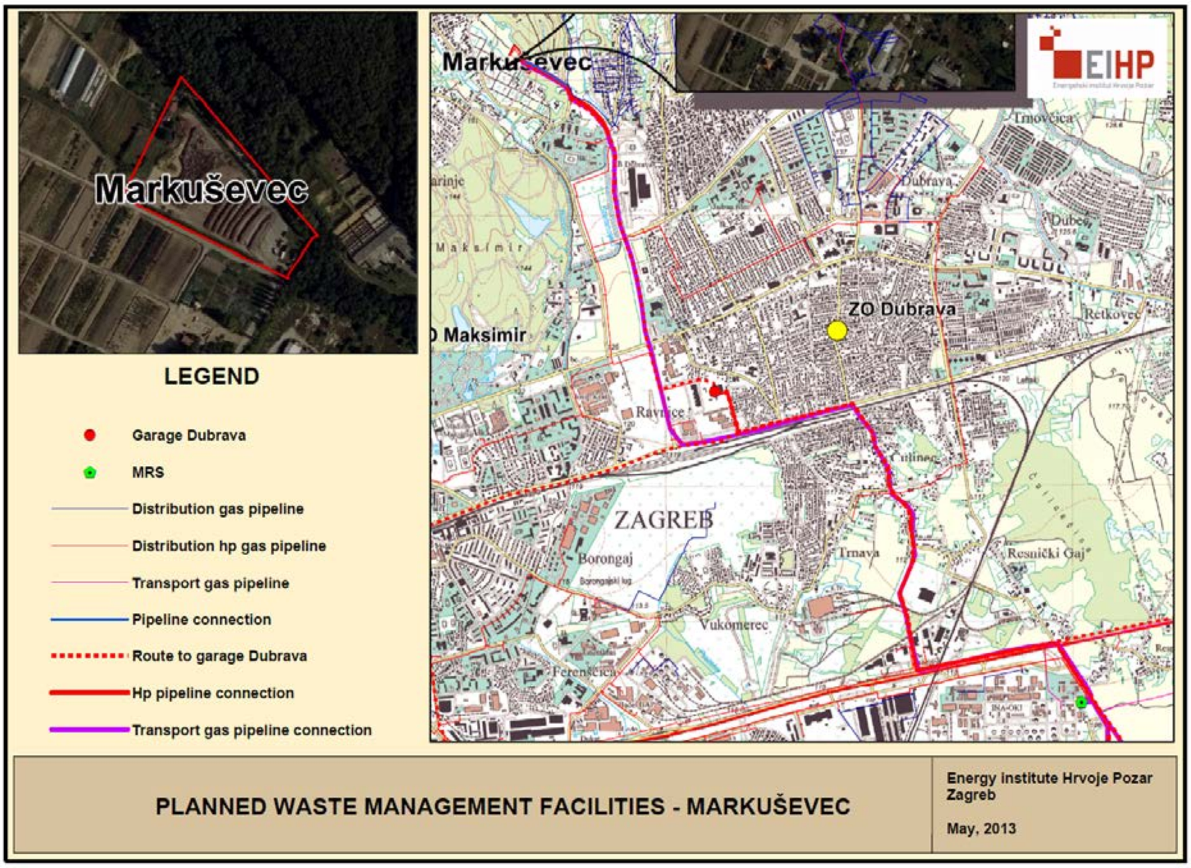



**Figure 33. Planned waste management facility - Markuševec**

1. **Dumovečki Lug -** suggested location for biogas plant in Draft Waste management plan (Proposed amendments to the Spatial Plan of the City of Zagreb 2012).

Regarding access to natural gas distribution grid; closest distance from the medium pressure network (4 bar, 110 mm) is 5 380 m and from the high pressure network (6 bar) is 2 908 m. Distance from transport gas pipeline connection is 4 676 m (MRS Ivanja Reka, 50 bar, 500-700 mm). Alternative to MRS Ivanja Reka is MRS Trstenik (4 053 m, 80 mm, 50 bar) Distance from the nearest ZET garage (planned CNG filling station) is 13 195 m (Dubrava).

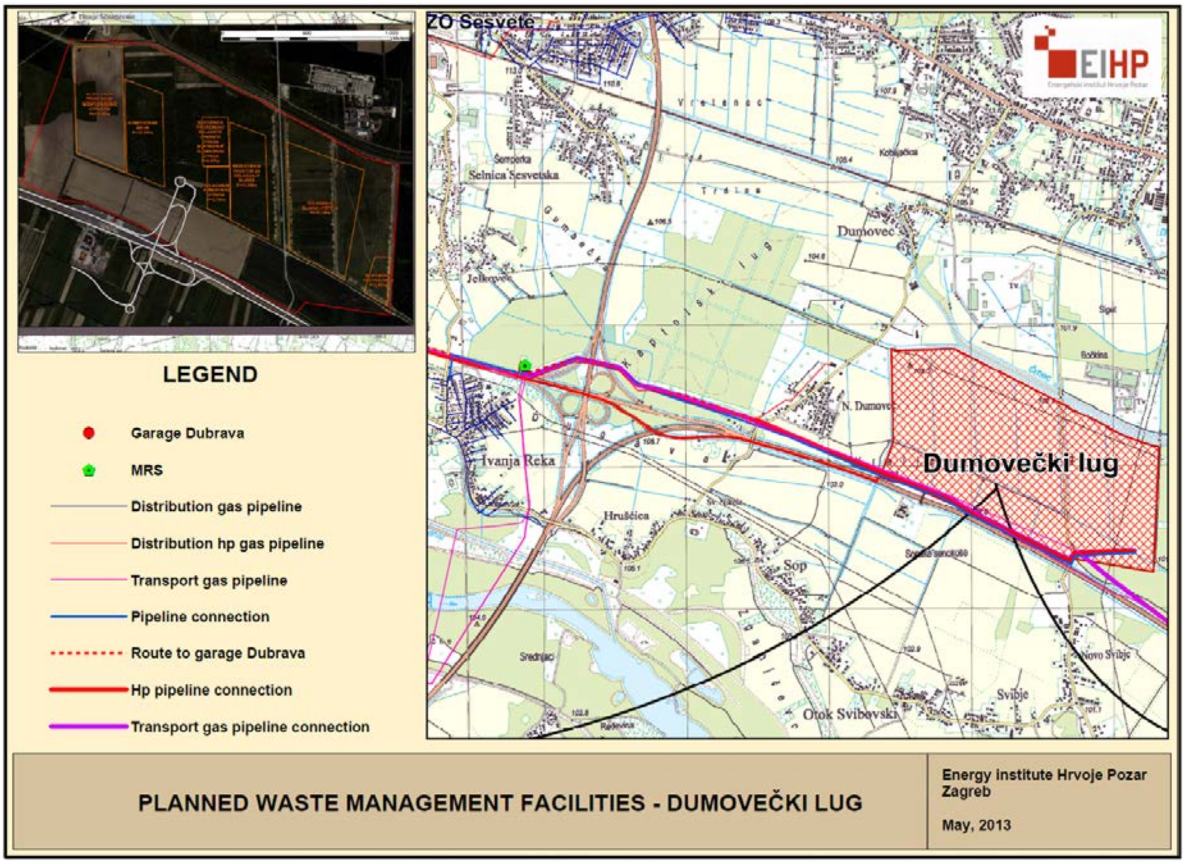



**Figure 34. Planned waste management facility Dumovečki Lug**

The length of gas network and the necessary investments for connection to the gas distribution and gas transmission system is shown below.

The connection cost for high pressure gas network is, depending on the location of biomethane production plant, 15 to 60% more expensive than the connection to the medium or low pressure gas network.

Connection to the gas transmission network is, depending on the location of biomethane production plant, 2 to 15 times more expensive than the connection to the gas distribution network.

Direct connection of Dubrava garage by high pressure pipeline to potential sites of biomethane production is 2 to 6 times more expensive than the plant's connection to the high pressure gas distribution network.

**Table 14. Connection to the gas distribution network - length and investments**

| LOCATION | Gas distribution network | | | Investment (EUR) | | | Total (EUR) | |
|---|---|---|---|---|---|---|---|---|
| | Middle/low pressure | | High pressure | Middle/low pressure | High pressure | Connection | Middle/low pressure | High pressure |
| | length, m | diameter, mm | length, m | | | | | |
| Prudinec | 4 324 | 225 | 5 215 | 432 400 | 778 320 | 140 000 | 572 400 | 918 320 |
| Resnik | 457 | 160 | 779 | 45 700 | 82 260 | 140 000 | 185 700 | 222 260 |
| Markusevec | 365 | 225 | 837 | 36 500 | 65 700 | 140 000 | 176 500 | 205 700 |
| Dumovecki lug | 5 380 | 110 | 2 908 | 538 000 | 968 400 | 140 000 | 678 000 | 1 108 400 |

**Table 15. Connection to the gas transmission network - length and investments**

| LOCATION | Gas transmission network | | | Investment (EUR) | | |
|---|---|---|---|---|---|---|
| | PRS | length, m | diameter mm | Pipeline | Connection | TOTAL |
| Prudinec | Zg Jug | 8 407 | 500 | 2 522 100 | 250 000 | 2 772 100 |
| Resnik | Zg Istok | 1 848 | 250 - 300 | 554 400 | 250 000 | 804 400 |
| Markusevec | Zg Istok | 8 254 | 250 - 300 | 2 476 200 | 250 000 | 2 726 200 |
| Dumovecki lug | Ivanja Reka | 4 676 | 500 - 700 | 1 402 800 | 250 000 | 1 652 800 |

**Table 16. Direct connection of Dubrava garage - length and Investments**

| LOCATION | ZET garage | | Investment (EUR) | | |
|---|---|---|---|---|---|
| | length, m | garage | High pressure | Connection | TOTAL |
| Prudinec | 10 428 | Dubrava | 1 877 040 | 140 000 | 2 017 040 |
| Resnik | 6 666 | Dubrava | 1 199 880 | 140 000 | 1 339 880 |
| Markusevec | 3 270 | Dubrava | 588 600 | 140 000 | 728 600 |
| Dumovecki lug | 13 195 | Dubrava | 2 375 100 | 140 000 | 2 515 100 |

According to the above-mentioned results and the criterion of the lowest cost, it could be assumed that the connection to the gas distribution network of medium or low pressure would be the most preferable option. However, the city of Zagreb has extremely developed high pressure gas network, to which bigger consumers with even annual gas consumption are mostly connected. High pressure gas network supplies medium or low pressure relatively small "islands" of consumption with gas to which are attached mostly households that have markedly seasonal consumption characteristics. On those medium or low pressure areas, natural gas consumption during summer months is several times lower than the average annual or maximum winter hourly consumption, and may be below the expected hourly consumption of biomethane plants, so the excess gas during this period should either be stored or flared.

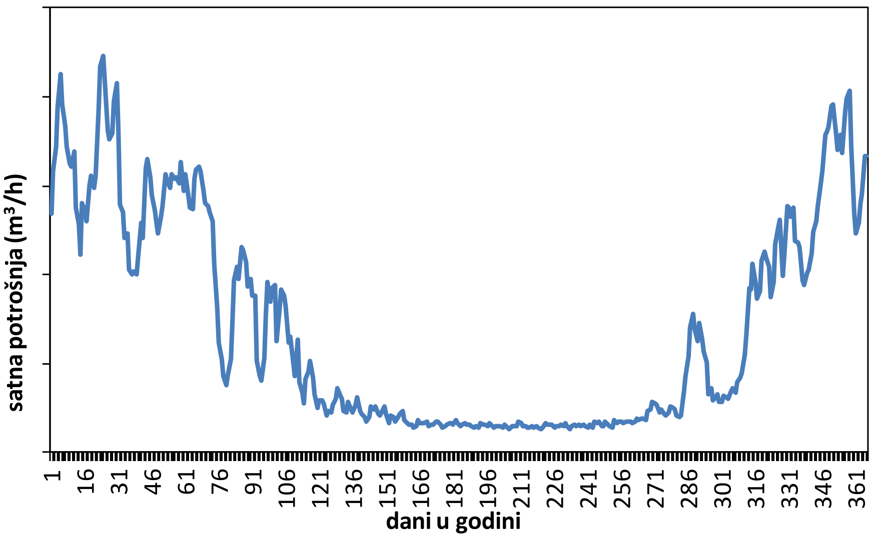



**Figure 35. Diagram of annual gas consumption in households**

***Legend:***

***satna potrošnja – hourly consumption***
***dani u godini – day in a year***

Given that the difference between the terminal at medium / low pressure and high pressure gas distribution system is not significant, and that biomethane by injection into a high pressure gas network will be available throughout the city, injection of biomethane into a high pressure gas network is proposed. Water scrubber or PSA technology with the working pressure above 6 bars is proposed as the technology for purification of biogas to biomethane

## 5.2 Public transport

For filling vehicles with natural gas there are generally two types of filling stations (slow and fast filling).

Slow filling stations - use the concept in which the compressor, directly connected to the gas network, compresses natural gas and directly fills a high-pressure tank of the vehicle through a flexible filling hose. The vehicle mustn't be started during the filling process. By the time a required level of pressure is reached, the compressor turns off automatically. Slow charging is recommended for fleets whose vehicles return to the central garage where they stay during the night, or for passenger vehicles using the so-called home filling that is mentioned below. The typical filling time is 6-8 hours. Thus, during periods outside their regular daily use (passenger cars, taxis, buses, forklifts, boats, etc ...) vehicles are filled directly.

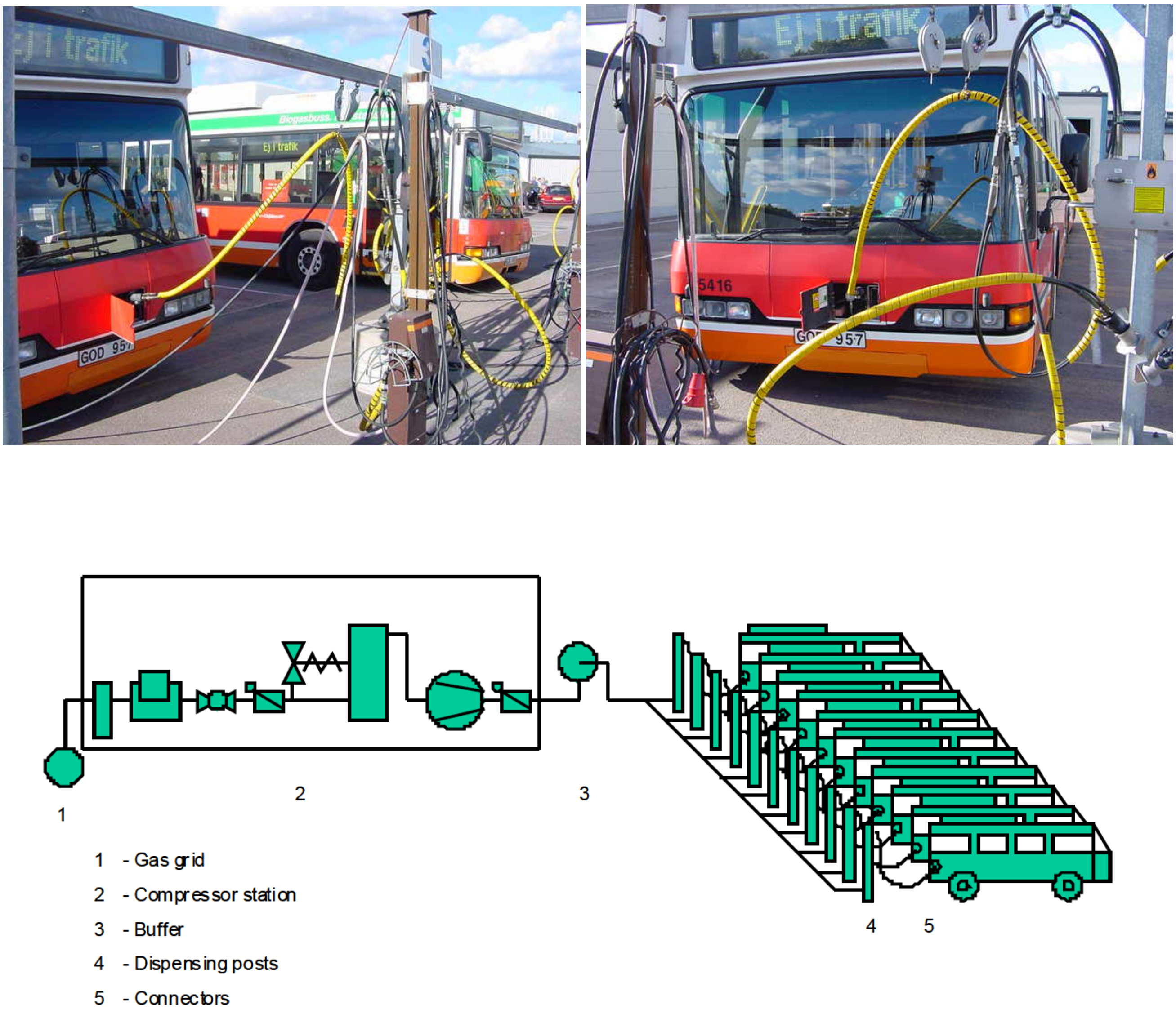



**Figure 36. Slow filling of vehicles (usually at night) directly through the compressor**

*Source: van Schoonhoven van Beurden G. (2004). Refuelling technology – Generic training 2004. Ingenieurbüro van Schoonhoven i ENGVA*

Fast filling stations – station for fast filling enables the same filling speed as in the case of conventional fuels usage (diesel and gasoline); 3 to 7 minutes for cars and vans.

Natural gas is compressed to a maximum pressure of 200 to 300 bar and stored in the filling tank. Initially, compressor charges the battery of high-pressure filling tanks. Through the dispenser, the vehicle is then filled with compressed gas for a period of several minutes, which is comparable with the duration of filling vehicles with classic motor fuels (natural gas or diesel). Emptied gas from the tank is then supplemented by a compressor. The amount of gas in the tank of a vehicle is up to 20% lower with fast filling compared to slow filling. The reason for this is that natural gas that enters the tank suddenly raises the pressure and oppresses the natural gas that is already in the tank. The consequence of a temperature rise in the tank is reduction of gas density, except in the case when a completely empty tank is being fast filled (then the temperature decreases rapidly at the beginning which partially compensates for its later rise).

The combination of fast and slow filling may be of interest to operators with a large fleet in which only part of the total number of vehicles need fast filling. A required storage capacity of a filling station is reduced in this way, which lowers the required investment costs.

The combination of fast and slow filling can also be used in cases when it is not possible to estimate at the start of the project with sufficient reliability how fast the demand for compressed gas will grow.

Filling station capacity can be expanded later. The construction of such a filling station reduces investment risk. The combination of fast and slow filling can be used to meet the needs of different groups of users: for example, external users can use fast filling, while the company's own vehicles can slowly fill overnight.

The main components of a "classic" filling station for fast filling are shown below. The basic difference between fast and slow filling stations is that slow filling stations don’t have high-pressure storage space and equipment for measuring the quantity of delivered compressed gas (if gas measurement even exists, it is usually at low or medium pressure gas input to the compressor) which makes them cheaper.

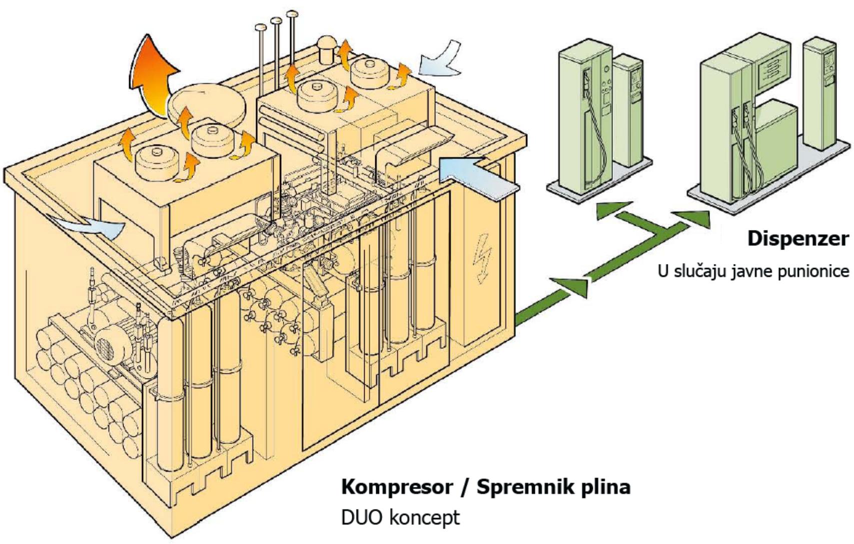


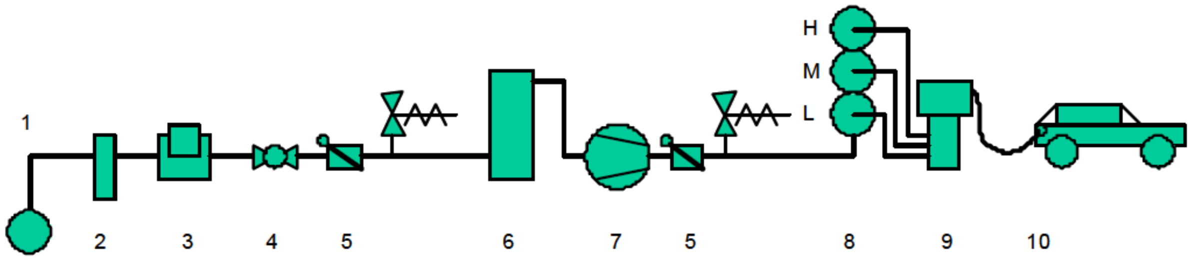

**Figure 37. Fast-fill compressed gas fueling station**

*Source: www.bauer-kompressoren.de*

It is imperative that compressed gas filling stations have the equipment that prevents the entry of compressor oil in tank of the vehicles, ensures that the gas is free of humidity and impurities, and that the level of sulfur in natural gas is at an acceptable level.

On today's market the following concepts of fast-fill fueling stations are available:

- fast-fill stations with piston compressor and 3 bank storage:

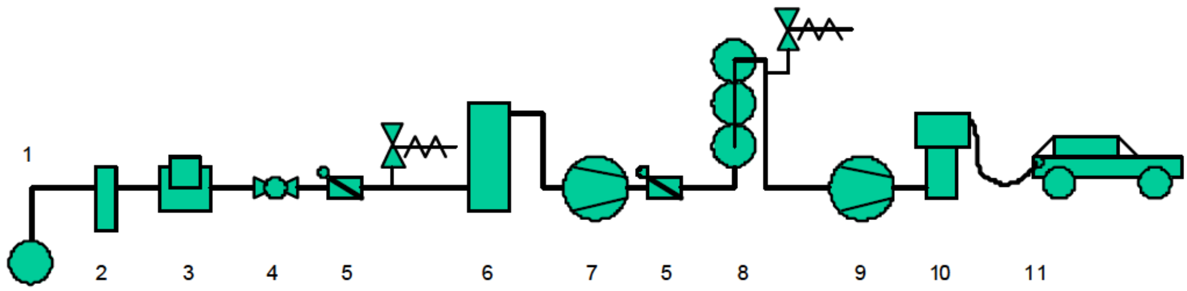



1 - Gas grid
2 - Gas filter
3 - gas meter
4 - Main valve
5 - Check valve
6 - Dryer
7 - Compressor
8 - Storage (3 Bank) 250 – 350 bar
9 - Dispenser
10 - Nozzle

**Figure 38. Fast-fill stations with piston compressor and three bank storage**

*Source: van Schoonhoven van Beurden G. (2004). Refuelling technology – Generic training 2004. Ingenieurbüro van Schoonhoven*

- fast-fill stations with piston compressor plus booster and 1 bank storage



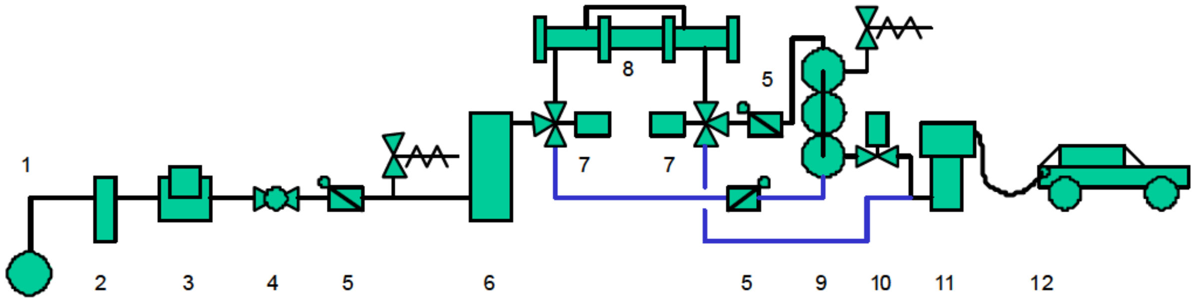

1 - Gas grid
2 - Gas filter
3 - gas meter
4 - Main valve
5 - Check valve
6 - Dryer
7 - Compressor
8 - Storage (1 Bank) 250 bar
9 - Booster
10 - Dispenser
11 - Nozzle

**Figure 39. Concept of a fast-fill station with piston compressor plus booster and a bank storage with one pressure level**

*Source: van Schoonhoven van Beurden G. (2004). Refuelling technology – Generic training 2004. Ingenieurbüro van Schoonhoven*

Additional compressor (booster) is used for further increase in the level of pressure, thus avoiding the need for use of tanks with three levels of pressure. Pressure at the output of the first compressor or bank storage (single-level pressure) presents the pressure at the input of the second compressor (booster). The main objective of the second compressor (booster) use is to shorten the time needed for filling vehicles. The decision to use the second compressor depends on the original input pressure at the first compressor (gas network pressure), the desired filling time and the number of vehicles that need to be served by the unit of time, and relation between purchase investments and maintenance costs of bank storage with three levels of pressure in relation to adding another compressor.

- Hydraulic compressor / booster:




1 - Gas grid
2 - Gas filter
3 - gas meter
4 - Main valve
5 - Check valve
6 - Dryer
7 - 3 way valve
8 - Hydr. Compressor / Booster
9 - Storage (1 Bank) 250 bar
10 - Solenoid valve
11 - Dispenser
12 - Nozzle

**Figure 40. Fast-fill fuelling station concept – hydraulic booster compressor and a bank storage with one pressure level**

*Source: van Schoonhoven van Beurden G. (2004). Refuelling technology – Generic training 2004. Ingenieurbüro van Schoonhoven*

One interesting concept that needs to be mentioned is the use of home refueling. Home refuelling (engl. 'Home Vehicle Refuelling Appliances' but better known under the abbreviation VRA) contains control system compressor, supporting electronics and software in a simple compact design. This system enables slow vehicle fuelling, and so far it has had the largest application in the United States where it can be installed as easily as an ordinary gas water heater. It is used primarily for fueling cars (which are used for transport to the workplace) during the night. Service interval of the compressor with existing models is approximately every 3,000 hours.

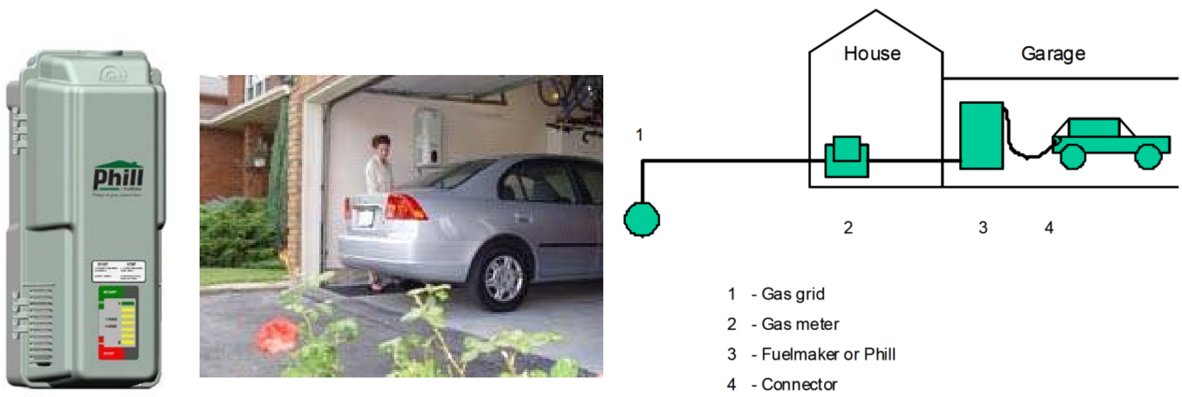



**Figure 41. Slow-fill CNG home refuelling station**

*Source: van Schoonhoven van Beurden G. (2004). Refuelling technology – Generic training 2004. Ingenieurbüro van Schoonhoven*

Currently, a new CNG filling station in ZET’s garage in Podsused is under construction, because the existing Zagreb City Gasworks filling station does not meet ZET’s demand.

The new filling station will be located within the existing diesel filling station of the AP Podsused Samobor cesta bb, Zagreb.

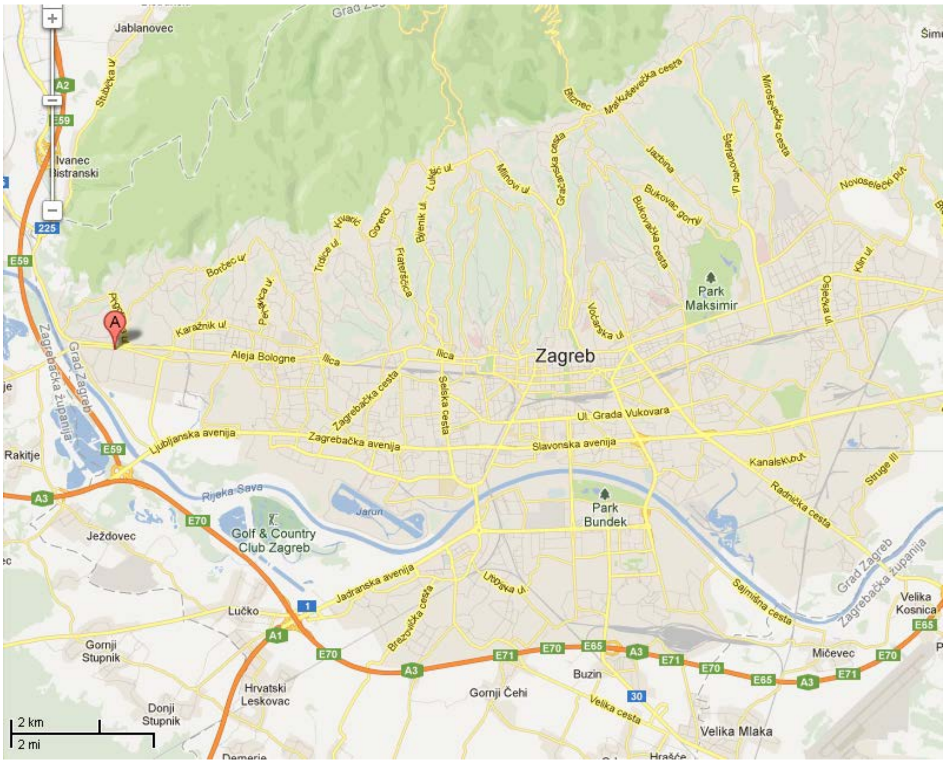



**Figure 42. Location of the ZET bus garage – Podsused (1)**


**Figure 43. Location of the ZET bus garage – Podsused (2)**

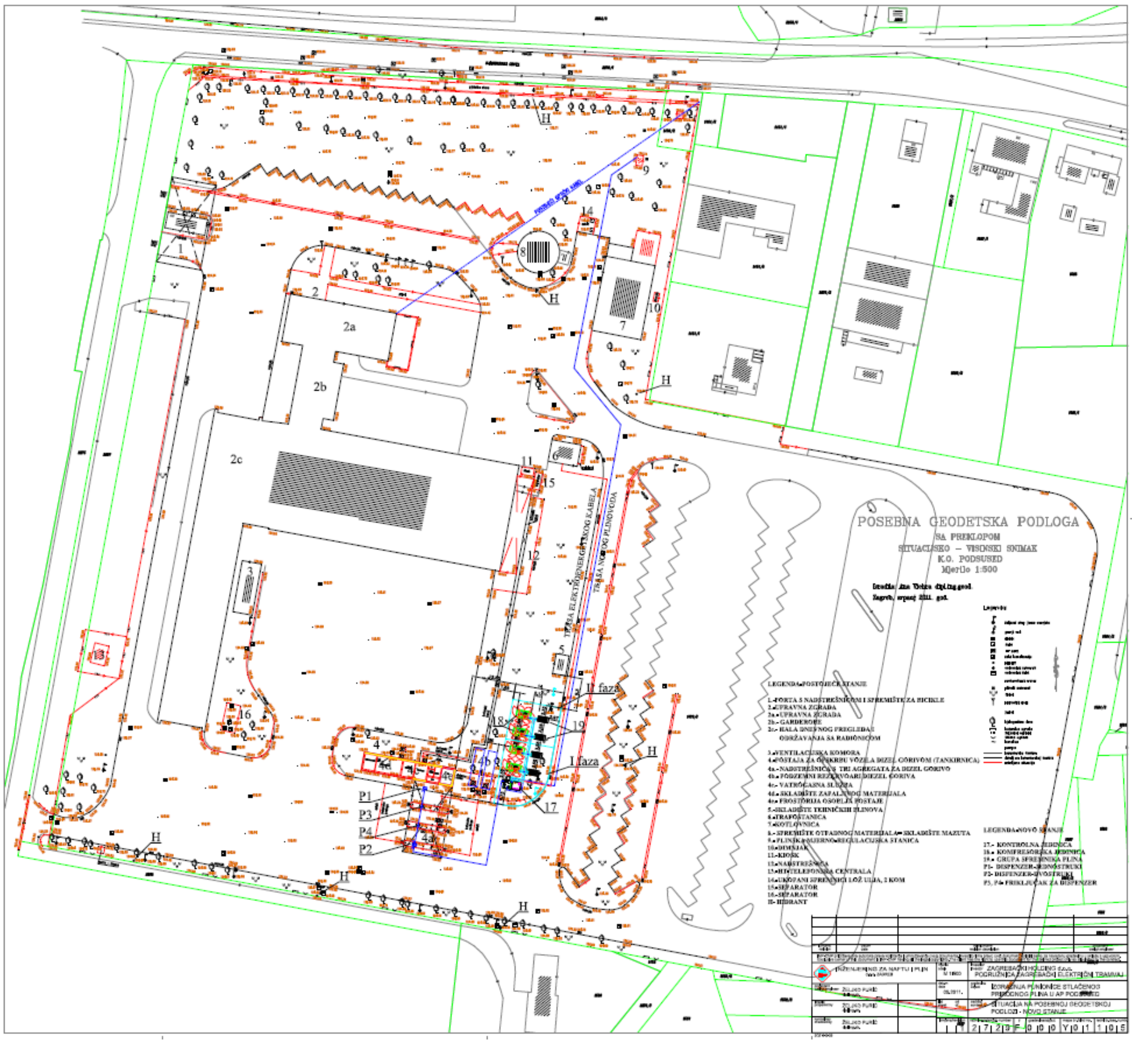
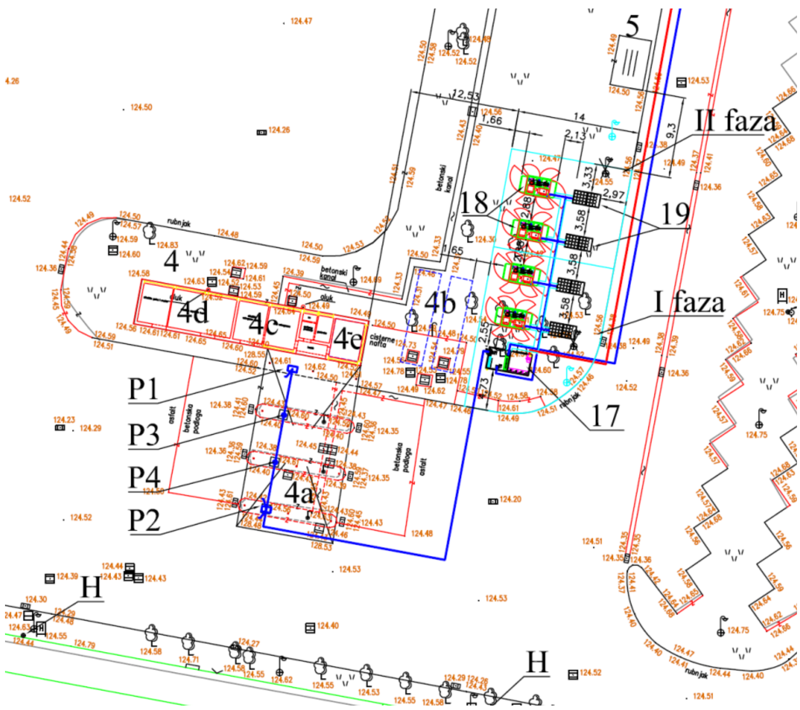



Figure 44. Current situational snapshot - ZET bus garage - Podsused




**4.- diesel filling station for vehicles (tank station)**
**4a.- canopy with three generators for diesel fuel**
**4b.- underground tanks of diesel fuel**
**4c- fire department**
**4d.- storage of flammable materials**
**4c- station staff room**
**5.- storage for technical gases**
**H- hydrant**
**17.- control unit**
**18.- compressor unit**
**19.- group of gas cylinders**
**P1- dispenser – single**
**P2- dispenser – double**
**P3,P4 - dispenser connector**

Figure 45. Planned CNG filling station on location Podsused

**Figure 46. ZET bus garage on location Podsused**

CNG filling station will be used primarily as an internal ZET filling station for a total of 60 buses, of which 40 are joint with engine power of 228 kW and 20 classic "solo" buses with engine power of 200 kW. Daily consumption should be covered by a single tank.

**Table 17. Basic specifications of bus tanks**

| | | CLASSIC „SOLO“ BUSES | JOINT BUSES |
|---|---|---|---|
| Tank volume | (l) | 1232 | 1540 |
| Pressure in the tanks | (bar) | 220 | 220 |
| Total tank capacity | (kg) | 185 | 231 |
| Tank capacity effectively | (kg) | 160 | 200 |

The construction of CNG filling stations will be performed in two phases. The first phase will incorporate two compressors with two groups of gas tank. In the second stage two additional compressors with another two groups of gas tank will be incorporated.

The necessary amount of CNG, required time and schedule for filling of 60 buses in the first phase is shown in the following table.

**Table 18. Filling cycles in the first phase (CNG filling station Podsused)**

| Filling period (hours) | Total buses (pcs) | | | Total CNG (kg) | | | CNG ($m^3$) | Max. bus refills (approx.pcs) |
|---|---|---|---|---|---|---|---|---|
| | solo | joint | total | solo | joint | total | total | |
| from 13 - 24 | 15 | 30 | 45 | 2400 | 6000 | 8400 | 12174 | 49 |
| from 00 – 03 * | 5 | 10 | 15 | 800 | 2000 | 2800 | 4058 | 15 |
| TOTAL | 20 | 40 | 60 | 3200 | 8000 | 11200 | 16232 | 64 |

***** period from 00 - 03 hours - maximum charging regime - 5 buses per hour

The maximum hourly consumption for the period 00-03 hours is 933 kg/h or 1353 $m^3$/h (1 $m^3$ = 0.69 kg of gas), and CNG station should be designed accordingly. Filling bus cycle consists of the necessary time for a bus tank filling and time to move the bus (the time required for the approach to the filling station and the time required to drive away). Total time of one tank filling should be up to 8 minutes and should not exceed 12 min.

The necessary amount of CNG, required time and schedule for filling of 60 buses in the second phase is shown in the following table (table presents the data for the first phase and second phase together).

**Table 19. Filling cycles in the second phase (CNG filling station Podsused)**

| Filling period (hours) | Total buses (pcs) | | | Total CNG (kg) | | | CNG ($m^3$) | Max. bus refills (approx.pcs) |
|---|---|---|---|---|---|---|---|---|
| | solo | joint | total | solo | joint | total | total | |
| from 13 - 24 | 8 | 22 | 30 | 1280 | 4400 | 5680 | 8232 | 80 |
| from 00 – 03 * | 12 | 18 | 30 | 1920 | 3600 | 5520 | 8000 | 30 |
| TOTAL | 20 | 40 | 60 | 3200 | 8000 | 11200 | 16232 | 110 |

***** period from 00 - 03 hours - maximum charging regime - 10 buses per hour

The maximum hourly consumption for the period 00-03 hours is 1840 kg/h or 2670 $m^3$/h (1 $m^3$ = 0.69 kg of gas), and CNG station should be designed accordingly.

Regarding input parameters, according to the data of distributor Zagreb City Gasworks Ltd., input pressure on filling station connector is 5-6 bar g. Available capacity on the existing high-pressure system is 3116 $m^3$/h. Dew point according to the "Contracting conditions for the supply of natural gas to eligible customers" INA d.d. is 10 °C at 50 bar.

CNG filling station will be connected to a derived high-pressure pipeline DN 100 in front of MRS ZET Podsused within AP Podsused. A new pipeline is planned from the existing high-pressure pipeline near MRS ZET Podsused to new CNG filling station.

Electric power consumers of CNG filling station will be provided with electricity from the existing transformer station TS 615 in AP Podsused, with cable laying from TS to the connector on the station.

**Expected investment cost for the first phase of the development amount to around 1 mil. EUR (filling station and connection pipeline)**

Zagreb City Gasworks – Supplies Ltd. and Zagreb Holding Ltd. (ZET), acting as partners and referring to the contents of "cooperation agreement" from May 2009, are headed for a revival of the project of compressed natural gas (CNG) filling station construction for public transport located at **AP ZET Dubrava**. Realization of the filling station project for ZETs bus fleet as soon as possible is of utmost importance for ensuring the conditions of availability and reliability of public transport, and Zagreb City Gasworks – Supplies Ltd. as the main supplier of gas in Zagreb County, see its interest in opportunity to expand natural gas consumption markets.

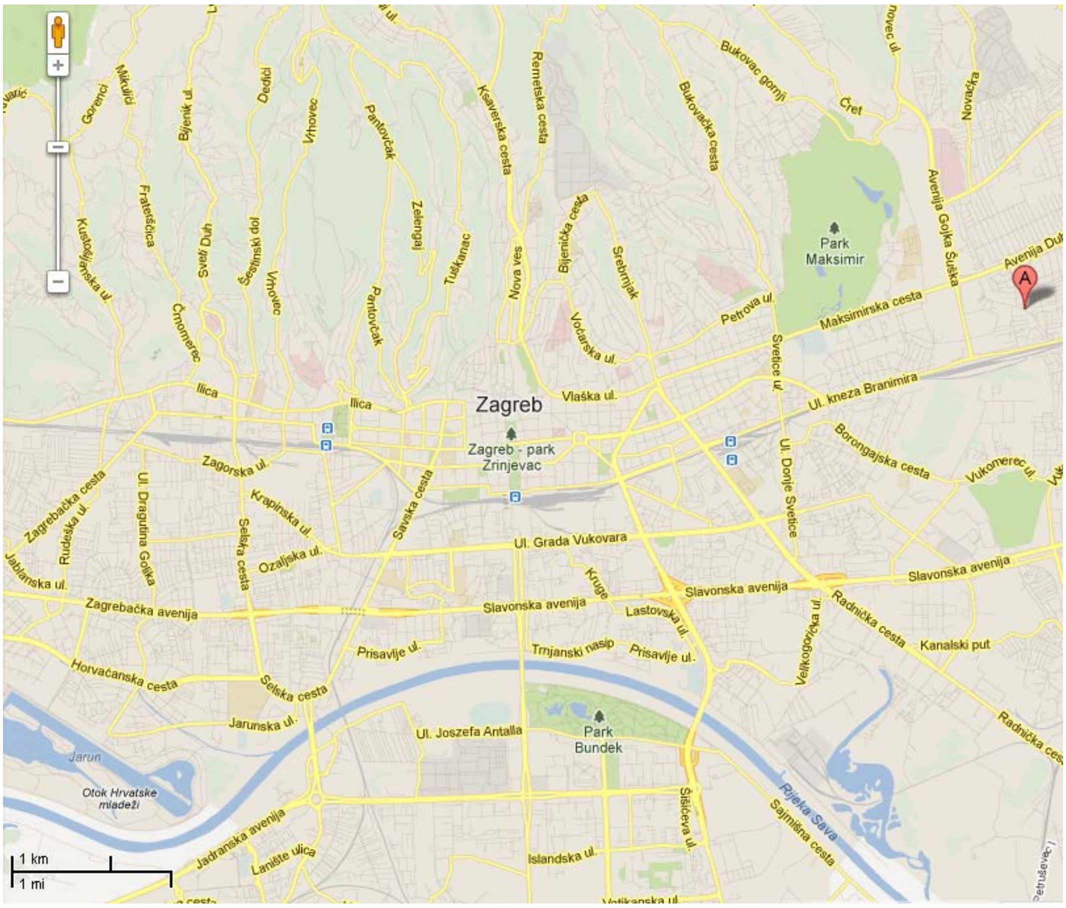



**Figure 47. Location of the ZET bus garage – Dubrava (1)**


**Figure 48. Location of the ZET bus garage – Dubrava (2)**

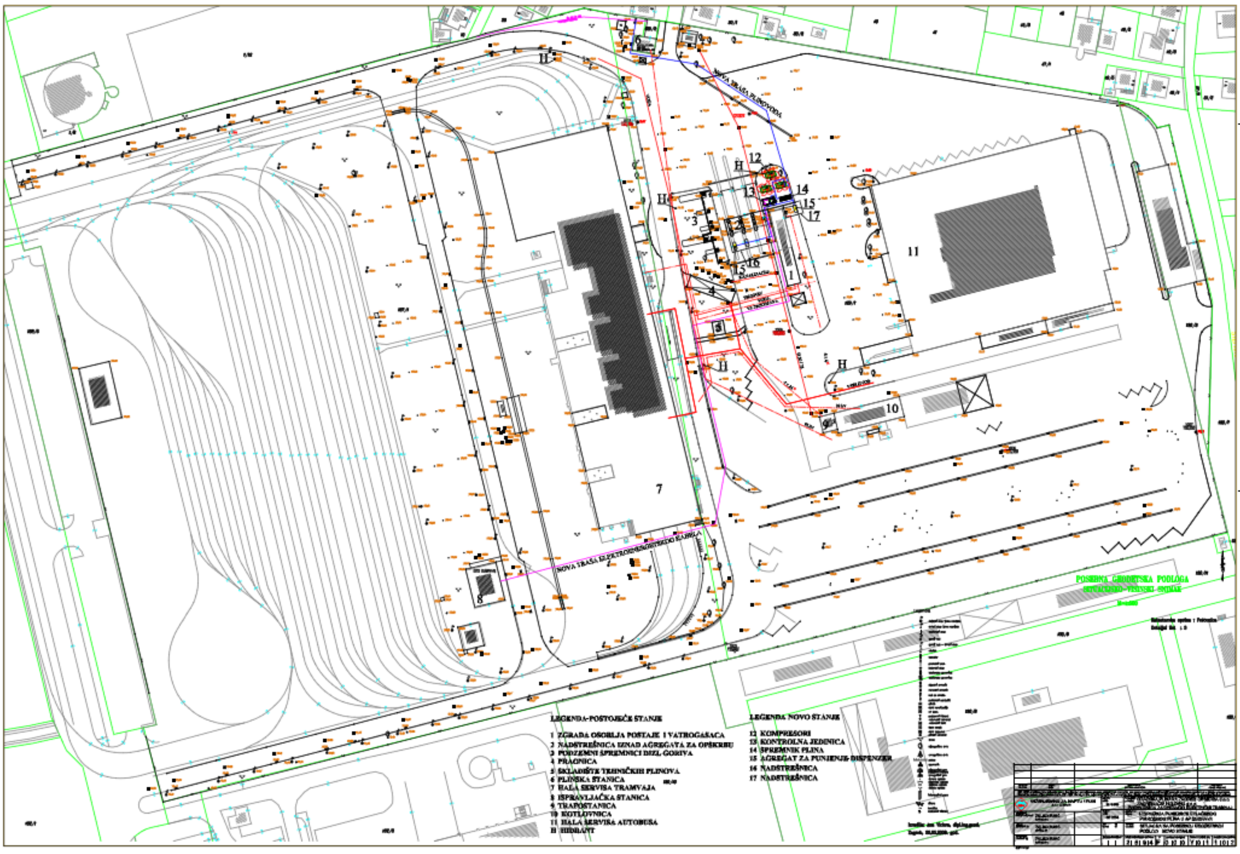
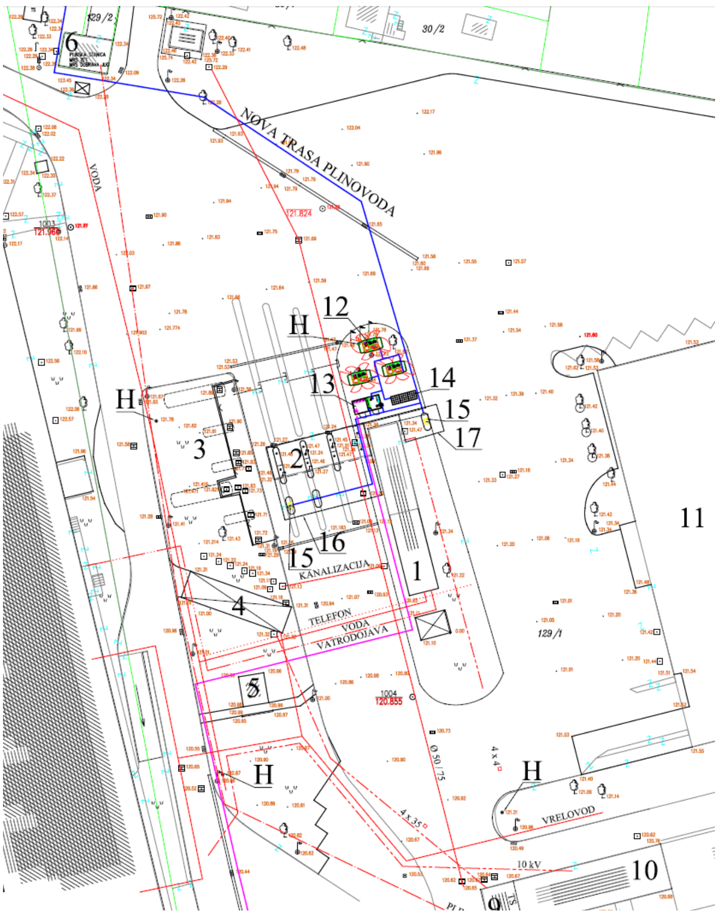


Figure 49. Current situational snapshot - ZET bus garage – Dubrava




1 station staff and firemen building
2 canopy over the supply aggregate
3 underground tanks of diesel fuel
4 car wash
5 storage for technical gases
6 gas station
11 a bus service
H- hydrant
12 compressors
13 control unit
14 gas tank
15 charging unit- dispenser
16 canopy
17 canopy

Figure 50. Planned CNG filling station on location Dubrava


**Figure 51.** ***AP ZET garage on location Dubrava 1***

In the same way as planned for Podsused filling station, the construction of CNG filling stations in Dubrava will be performed in two phases too.

The necessary amount of CNG, required time and schedule for filling of 60 buses in the first phase and total of 100 busses in second phase is presented in the following tables.

**Table 20. Filling cycles in the first phase (CNG filling station Dubrava)**

| Filling period (hours) | Total buses (pcs) | | | Total CNG (kg) | | | CNG ($m^3$) | Max. bus refills (approx.pcs) |
|---|---|---|---|---|---|---|---|---|
| | solo | joint | total | solo | joint | total | total | |
| **from 8 - 12** | 4 | 11 | 15 | 640 | 2200 | 2840 | 4116 | 40 |
| **from 17 – 24 *** | 4 | 11 | 15 | 640 | 2200 | 2840 | 4116 | 70 |
| **from 00 - 03** | 12 | 18 | 30 | 1920 | 3600 | 5520 | 8000 | 30 |
| **TOTAL** | 20 | 40 | 60 | 3200 | 8000 | 11200 | 16231 | 140 |

***** period from 00 - 03 hours - maximum charging regime - 10 buses per hour

The maximum hourly consumption for the period 00-03 hours is 933 kg/h or 1353 $m^3/h$ (1 $m^3$ = 0.69 kg of gas), and CNG station should be designed accordingly. Filling bus cycle consists of the necessary time for bus tank filling and time to move the bus (the time required for the approach to the filling station and the time required to drive away). Total time of one tank filling should be up to 8 minutes and should not exceed 12 min.

The necessary amount of CNG, required time and schedule for filling of 60 buses in the second phase is shown in the following table (table presents the data for the first phase and second phase together).

**Table 21. Filling cycles in the second phase (CNG filling station Dubrava)**

| Filling period (hours) | Total buses (pcs) | | | Total CNG (kg) | | | CNG ($m^3$) | Max. bus refills (approx.pcs) |
|---|---|---|---|---|---|---|---|---|
| | solo | joint | total | solo | joint | total | total | |
| from 8 - 12 | 11 | 17 | 28 | 1760 | 3400 | 5160 | 7478 | 40 |
| from 17 – 24 * | 17 | 25 | 42 | 2720 | 5000 | 7720 | 11188 | 70 |
| from 00 - 03 | 12 | 18 | 30 | 1920 | 3600 | 5520 | 8000 | 30 |
| TOTAL | 40 | 60 | 100 | 6400 | 12000 | 18400 | 26666 | 140 |

***** period from 00 - 03 hours - maximum charging regime - 10 buses per hour

The maximum hourly consumption for the period 00-03 hours is 1840 kg/h or 2700 m³/h (1 m³ = 0.69 kg of gas), and accordingly CNG station should be designed.

Regarding input parameters, distributor Zagreb City Gasworks Ltd. guarantees the pressure on filling station connector of 4-6 bar g. Project input pressure in filling station system should be 5.5 bar g.  Dew point according to the "Contracting conditions for the supply of natural gas to eligible customers" INA d.d. is 10 °C at 50 bar.

Special conditions of connection to gas and distribution network and energy approval should be provided by Zagreb City Gasworks Ltd. In principle, the filling station will be connected to a high-pressure gas pipeline in front of Zagreb City Gasworks control station for ZET and regulation station Dubrava-south. Based on technical data on existing installations and energy data on their electricity consumption and peak load achieved, HEP Distribution System Operator allows the connection of planned installations within the existing power installations of ZET if its power does not exceed 600 kW.

Prices of petroleum products, which have been valid in Croatia from 13 May 2013, are shown in the following table. It is evident that the economic savings of using natural gas as an alternative fuel are significant.

**Table 22. Prices of petroleum products at filling stations (13.05.2013 – Croatia)**

| FUEL | PRICE (kn/l) | (kn/kWh) |
|---|---|---|
| BMB EURO BS 95 | 9.95 | 1.04 |
| BMB EURO BS 95 | 9.99 | 1.04 |
| BMB EURO BS 98 | 10.3 | 1.08 |
| DG EURO BS | 9.19 | 0.92 |
| DG EURO BS CLASS | 9.23 | 0.92 |
| LPG | 4.69 | 0.65 |
| Natural gas commercial | | 0,5 |
| City Gasworks CNG | 7.5 kn/kg | 0.56 |

Natural gas price is cheaper than diesel fuel by 45% (DG EURO BS) and City Gasworks Supply CNG is cheaper than diesel fuel by 38%. If we take into account that ZET might buy diesel fuel at wholesale discount price, then the difference of natural gas or CNG to diesel might be smaller.

# 6 Economic and organisational considerations

## 6.1 Grid injection

The potential cost of biomethane at the connecting pipeline depends on the specific cost of waste collection and processing, production and purification of biogas to biomethane. Considering that the concept of waste disposal was created in scenarios, and for that reason it was too complex to calculate the cost of biogas, in this section we are going to use specific prices from Germany increased by 30% (the impact of developing markets and lack of technology). In this way, the calculated cost of biomethane would amount to 0.5 - 0.7 kn / kWh.

The price of gas transmission and injection into natural gas distribution network would, according to the simplified calculation (simple return of investment in 10 years) for the expected production of biogas, be 0.007-0.035 kn / kWh (depending on the production scenario and the distance of location from the gas network).

**Table 23. Biomethane injection costs to distribution network**

| LOCATION | Investment (kn) | Biomethane production (kWh) | | | | Connection costs (kn/kWh) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | S1 | S2 | S3 | S4 | S1 | S2 | S3 | S4 | average |
| Prudinec | 6 887 400 | 10 483 333 | 35 133 333 | 33 716 667 | 65 638 889 | 0.066 | 0.020 | 0.020 | 0.010 | 0.029 |
| Resnik | 1 666 950 | 10 483 333 | 35 133 333 | 33 716 667 | 65 638 889 | 0.016 | 0.005 | 0.005 | 0.003 | 0.007 |
| Markusevec | 1 542 750 | 10 483 333 | 35 133 333 | 33 716 667 | 65 638 889 | 0.015 | 0.004 | 0.005 | 0.002 | 0.007 |
| Dumovecki lug | 8 313 000 | 10 483 333 | 35 133 333 | 33 716 667 | 65 638 889 | 0.079 | 0.024 | 0.025 | 0.013 | 0.035 |

The price of biomethane at the entry to gas distribution network would amount to between 0.51 and 0.74 kn/kWh. The above price is considerably higher than the price of natural gas at the entry to the gas distribution network, which is about 0.24 to 0.37 kn/kWh.

## 6.2 Public transport

The expected investment for the construction of one natural gas filling station at Podsused location amounts to approximately EUR 1 million for the first phase, and the total investment for the first and second phase might be between 1.5 and 1.7 million. Unlike evaluation of specific cost of connection systems, the evaluation of specific cost of gas filling station is much more complex. In operation of gas connections, dominant part is presented by investment costs, while the operation and maintenance cost is almost negligible. Gas filling station operation and maintenance costs have a significant impact on the final specific price of gas filling. It primarily depends on the fuel used to drive the compressor and on the regime of filling station operation. A detailed economic and financial analysis related to the use of compressed natural gas in the area of Zagreb has been conducted. The cost of construction, operation and maintenance of the filling station, depending on capacity and level of utilization, is between 0.06 and 0.14 kn / kWh.

The price of gas distribution in the city of Zagreb is 0.039 kn/kWh. Based on the above-mentioned indicators, the total price of biomethane at the exit of the filling station would amount to between 0.61 and 0.91 kn/kWh, excluding VAT. The above price is in its smaller amount lower than the cost of diesel fuel or gasoline, but in its larger amount it is higher than the price of motor fuel.

## 6.3 Organizational aspects

Under the Law on Gas Market, which refers to all gaseous fuels transferred by gas system including biomethane, energy activities are:

1. gas production,
2. natural gas production,
3. gas transmission,
4. gas storage,

5. managing of UPP terminal
6. gas distribution,
7. gas market organization,
8. gas trading and
9. gas supply.

For the delivery of biomethane to the final consumer in terms of organization, participation of following activities is necessary:

1. gas production,
6. gas distribution,
8. gas trading and
9. gas supply.

Gas distribution is a regulated activity performed in the City of Zagreb by City Gas Works Company.

For performing energy activities it is necessary to meet legal requirements and obtain permission from the Regulatory Agency (HERA).

To obtain a specific permit, energy operator is required to demonstrate compliance with prescribed conditions for performing an activity:

- proof that it is registered for carrying out energy activities, if the Agency by inspecting relevant public registry can not establish that a natural or legal person (corporation) is registered for performing an energy activity
- proof that it is technically qualified for carrying out energy activities,
- proof that it is professionally qualified for carrying out energy activities,
- proof that it is financially qualified for carrying out energy activities,
- statement from a responsible person that Members of the Board and their corporation subordinates were not convicted in the past five years of a crime against the economy, certified by a notary public, or a statement from a natural person/individual that he has not been convicted of a crime against the economy in the last three years, certified by a notary public,
- proof of payment of license fees prescribed by the Decision of the amount of compensation for the performance of energy activities

Producer of biomethane can participate independently in a wide range of activities, for which he must meet the requirements and obtain all necessary licenses or obtain a license to produce gas and sell it to companies for gas trade and supply.

Presently, Zagreb Holding encompasses the branches for waste collection and management and public transport in Zagreb (ZET), and is the owner of the company for gas trade and supply (Zagreb City Gas Works - Supply).

Therefore, we suggest that the biomethane producer registers for gas production only, hand over the biomethane through long-term contracts to the company for gas trade and supply (Zagreb City Gas Works - Supply) that will deliver it through the distribution network to the ultimate consumer / consumers where, from the standpoint of the City of Zagreb, it can achieve the greatest benefits in terms of the obligations related to renewable energy sources in the City of Zagreb.

# 7 Legal requirements for biomethane use

Natural gas has been used to some extent as a fuel for internal combustion engines in compressor stations, co-generation systems, and vehicles of various types for many years now. However, the prerequisites for growth, i.e. economic viability and fuel availability, were generally not satisfied. Now, with the natural gas industry well established, and the need for alternative, low emission fuels, the situation has improved considerably. During the past decade, natural gas vehicles have become a viable option with some five million units now in use around the world. Growth is continuing as many governments actively promote this clean-burning fuel with its environmental benefits. Many fleet operators are converting their vehicles, and vehicle manufacturers are developing and marketing dedicated natural gas equipment.

International Standard (**ISO 15403**) for the quality designation of compressed natural gas is designed to stipulate the international requirements placed on the natural gas used as a motor fuel. Engine and vehicle manufacturers must know these requirements so they can develop high performance equipment which runs on compressed natural gas.

In the context of this International Standard, natural gas vehicles (NGVs) utilize compressed natural gas stored “on-board”. The pressure of the gas stored in multiple containers is up to a maximum 25000 kPa. Although the pressure has to be reduced before combustion, compression and storage gives NGVs an adequate range. While NGVs were initially equipped with converted gasoline or diesel engines, high performance, dedicated natural gas engines are now being extensively developed and produced.

Croatian legal framework does not recognize biomethane as a fuel. According to the law, biogas is defined as gaseous fuel produced from biomass and / or from the biodegradable fraction of waste, that can be purified to natural gas quality, to be used as biofuel for blending with natural gas or wood gas. For this reason, when we talk about the use of biogas in traffic we mean biomethane.

Croatian legal framework that describes utilisation of energy from biogas is not sufficiently elaborated to allow maximal utilisation of biogas. Biogas is described in some 40 legal documents that could be arranged in three main categories: energy, agriculture and environmental protection. Within energy policy, biogas is described as one of RES while in other policies, biogas is positioned as a tool for achieving a specific goal of agriculture policy (say, a rural development measure) and environmental policy (say, a GHG emissions saving tool, agriculture pollution prevention measure).

One of the most important bottlenecks for Croatian biogas market development in general is lack of knowledge within responsible bodies on biogas properties. Biogas is the most versatile of all RES, both in terms of potentials (substrates) and useful energy forms. It is only RES that participates in all energy markets: electricity, heat, natural gas, transport. This versatility calls for synchronised measures in order to either maximise (the best energy conversion efficiency) or optimise (according to energy planning demand) utilisation of biogas potential.

In strategic documents, biogas potential is under-estimated as it is based on manure monodigestion of 20% total livestock units. The vast spectrum of available substrates has been completely disregarded: waste and by-products of agro-food industry, organic part of municipal waste, "ex-food", waste sludge from waste water treatment plants as well as energy crops. Final version of **NREAP** is missing which should specify what desirable forms of biogas useful energy are, including biogas heat.

Currently, biogas production has two, mutually exclusive, incentives: FiT for RES-E from biogas (set of laws from energy) and 50% grant in investment for building and/or reconstruction of a biogas plant (set of laws from agriculture). Law on RES-H has been pending since 2008.

**The Energy Development Strategy** states that the Republic of Croatia, due to favorable effects on the reduction of emissions into the environment, will encourage the use of compressed natural gas (CNG) in transport. Place of its use are truck corridors (blue corridors) and city buses, as well as car traffic. Application of CNG in traffic opens the possibility of the application of compressed biomethane which will be especially stimulated, because it facilitates the fulfillment of obligations of renewable energy sources in transport.

Today, biogas is recognized in a legislation that describes biofuels, but its use in the production or transportation is still not stimulated.

**Law on biofuels for transport** (**NN 145/2010**) encourages the production of following biofuels (Article 20): (1) biodiesel from rapeseed, used cooking oils and lignocellulosic raw materials, (2) bioethanol from corn, sugar beets, and lignocellulosic materials (3) biogas and (4) biomethanol. However, the encouraging model has been developed only for biodiesel and bioethanol.

According to the Law, user of fuel in public transport and public sector shall ensure that in each year at least 70% of newly purchased or leased vehicles or boats use:

1. biofuel blended into diesel or petrol at a share of more than 5% or
2. biodiesel in the form of pure biofuel or
3. biogas in the form of pure biofuel or
4. hybrid power or
5. electric power or
6. hydrogen.

According to the law the county and major cities are required to develop and adopt a Program to encourage the production and use of biofuels in transport. The program is a planning document that is adopted for a period of three years, in accordance with the National Action Plan to encourage the production and use of biofuels in transport for the period of 2011- 2020. The program, among others, should include the review and assessment of the present condition and the needs of the market in fuel consumption for transportation in the county, comparative analysis, long-term goals, measures to encourage increased production and use of biofuels in transport, etc.

In achieving the goals of the share of biofuels in transport, biofuels energy produced from wastes, residues, non-food cellulosic material and lignocellulosic material is taken twice a value higher than actual consumption.

According to the National Action Plan to encourage the production and use of biofuels in transport for the period of 2011- 2020, 9.81 percent of the total fuel consumed in traffic should be biofuels. Of this, the share of biogas should be 0.62 percent or 8.466 million administrative $m^3$ of biogas from waste, or in energy units, 4.233 million $m^3$. During the year 2011, 16 mil. $m^3$ of bigas was already produced in Croatia, which represents about 8 million $m^3$ of biomethane. According to this document, as part of measures to encourage the production of biofuels for transport, conducting necessary research is predicted and the system to encourage production of compressed biomethane will be defined in accordance with the results. According to the National Action Plan, preparation and adoption of the Decree on the promotion of biogas production for transportation and admission of biogas use within the promotion of compressed natural gas use for transportation, has been predicted only for the period after 2016.

GUP (General Spatial Plan) of city of Zagreb prescribes the condition of building the gas stations. It shows existing and planned gas stations. Locations of planned petrol stations are provisional. Petrol stations can be built on other sites, provided that they are located:

- in mixed, mostly business use area, the size of a building plot of 2000 $m^2$, with mandatory 20% of the natural terrain of the building plot to be arranged as a complete green horticultural area according to existing or planned buildings adjacent to the building plots;
- in economic purpose;

- In the areas of infrastructure systems.

Reconstruction and construction of new petrol stations in the corridors of roads is possible with the opinion of the City Institute for Physical Planning.

Existing and planned gas stations can be reconstructed and constructed so as to ensure:

- the safety of all road participants;
- environmental protection by regulation of at least 20% of the building plot as a whole horticultural area, with preliminary design forming a protective green belt.

Petrol stations may have supporting facilities in the function of street traffic.

The regulations of this decision relating to the construction of gas stations are also applicable for the construction of CNG filling stations for motor vehicles, which makes CNG station development very complicated.

GUP (General Spatial Plan) of city of Zagreb prescribes the condition of building the gas supply systems.

General Urban Plan defines areas and corridors for the construction of:

- the main high-pressure gas pipeline ∅ 600, 75 bar, which will be built for needs of INA, with existing VT pipeline along the city's bypass, from Lučko to the new PPMRS - East, Ivanja Reka, which should provide a corridor of 30 m on both sides of axis of the pipeline;
- gas transceiver measuring-reduction stations; the main high-pressure gas pipeline Ivanja Reka - TE-TO Zagreb under the jurisdiction of City Gasworks and distribution of high-pressure pipelines;
- gas regulation stations (PRS) and transmition (RS) and blockade station (BS).

Gas regulation stations (PRS) are overhead or underground structures. If necessary, around some of them is placed a protective fence outside the danger of explosion. Just next to them are placed high-pressure lines (HPP) or medium-pressure pipelines (MPP), and from them to the consumer medium-pressure water pipelines (MPP) or low-pressure pipelines (LPP). Location of PRS must have an access road to public traffic area with one parking space for occasional parking of personal or commercial vehicle.

Transmition (RS) and blockade station (BS) are built above ground. Around them, if necessary, a safety fence is set outside the danger zone of explosion. Location of RS and BS must have an access road to public traffic area with one parking space for temporary parking of personal or commercial vehicle.

Gas pipelines are buried underground at a depth of 1m minimum, from the overlay up to the level of landscaped grounds.

Minimum safety distances from sensitive neighbouring buildings are:

- Pipeline Ivanja Reka - TE-TO Zagreb 30 m from the axis of the pipeline;
- RS, BS, PRS 10 m and 3 m public traffic area;
- HPP 10 m;
- MPP 2 m;
- LPP 1m.

Minimum safety distances from sensitive neighbouring buildings for HPP, MPP and LPP may be reduced in exceptional and duly justified cases, with additional use of special safeguards and consent of City Gasworks Zagreb.

In parts of the city where, along the gas distribution network, other energy sources exist or are planned, energy source that is more acceptable to the consumer will be used.

When planning biomethane pipeline connections to the gas network, the above mentioned obligation should be followed, and pipelines should be planed within the new GUP.

City of Zagreb spatial plan recognize energy savings and efficiency, the introduction of gas, expanding the CTS and the development of additional alternative energy as a measure of protecting and improving air quality.

## 7.1 Grid injection

In Croatia there is overarching legal framework for the production of biomethane from biogas and its injection into the natural gas network in compliance with applicable rules stemming from the **Gas Market Act (NN 40/07, 152/08, 83/09, 114/11).**

The rules established by this Act and the regulations issued there under are applicable to biogas, gas from biomass and other types of gas if these types of gases can be safely transported through the gas system.

**Network Gas Distribution System rules (NN 50/09)** permit blending of the biogas, gas from biomass and other types of gas with natural gas, but only if these types of gases can be safely added to the flow, and if the resulting gas mixtures can technically and safely be distributed through the distribution system. Biogas or gas mixtures shall meet the standard quality natural gas from **Appendix 1** of the **General Conditions of Energy Supply of natural gas (NN 43/2009).** Gas blending is approved by the Distribution System Operator.

Implementing regulations to provide a simple and transparent way to the consumer, such as biomethane technical requirements for biomethane injection, positive discrimination towards the use and / or injection of biomethane into the natural gas network, payment terminal, etc. are currently lacking.

By the end of 2012 in eleven European countries biogas was upgraded to biomethane. In nine countries thereof biomethane was injected into the grid. Sweden and Switzerland have the longest experience which started back in the early 90s. All of the biomethane countries developed standards for injection (plus some more countries not injecting biomethane yet). However, a lot of differences could be found in fundamental aspects such as parameters and/or concentrations of compounds other than methane, with variations even up to a factor of 100 (i.e. for mandated oxygen levels).

According to the GrinGasGrids project, in Europe and also in Croatia, a number of points are still open for discussion, either because reliable data are still to be compiled or because the relevant data are not available yet and must be part of future research projects:

- Sulphur
- Siloxanes
- Trace components that may (or can) have an effect on health
- Exposure models for these trace components
- Oxygen
- Hydrogen
- Methane number (parameter linked to the risk of knocking in engines, cf. octane number for liquid fuels). In the case of insecurity preliminary figures will be used in the standard that will subsequently be adapted. There is still dispute if these values will arbitrarily be set at a low value and weakened afterwards if possible or if they should be set at the upper limit of known band width and subsequently be reduced if necessary.

The following table shows a comparison of the quality of natural gas between countries. It is obvious that in Croatia a plenty of data is still missing or not defined.

**Table 24. Standard gas quality (GrinGasGrids project)**

| | | Austria | Germany | Switzerland | France | Netherlands | Croatia |
|---|---|---|---|---|---|---|---|
| Wobbe index | MJ/m3 | 47,88-56,52 | 37,8-56,5 | 47,88-56,52 | 43,24-56,5 | 43,46-44,41 | 41-55 |
| Calorific value | MJ/m3 | 38,52-46,08 | 30,2-47,2 | 38,16-47,16 | 34,2-46,08 | 31,6-38,7 | 33,1-44,3 |
| Specific density | | 0,55-0,65 | 0,55-0,75 | | 0,555-0,7 | | |
| Water | mg/kg | | 40 | | | | |
| Dewpoint water | °C | | | -8 | -5 | -10 | -10 |
| $CH_4$ | Vol % | | | >96 | | | >85 |
| $CO_2$ | Vol % | 2 | 6 | 6 | 2 | | |
| $N_2$ | Vol % | 5 | | | | | 7 |
| $O_2$ | Mol % | | | | | 0,5 | |
| CO | Vol % | | | 0,5 | 2 | | |
| $H_2$ | Vol % | 4 | 5 | 4 | 6 | 12 | |
| S total | mg/m3 | 10 | 30 | 30 | 30 | 45 | 100 |
| $H_2S$ | mg/m3 | 5 | 5 | 5 | 5 | 5 | 7 |
| Mercaptans | mg/m3 | 6 | 6 | 5 | 6 | 10 | - |
| Siloxanes | mg/m3 | 10 | | | | 5 | |
| $NH_3$ | mg/m3 | 0 | | 20 | 3 | 3 | |
| Hg | µg/m3 | | | | 1 | | |
| Cl | mg/m3 | | | | 1 | 50 | |
| F | mg/m3 | | | | 10 | 25 | |
| Heavy metals tot. | mg/m3 | | | 5 | | | |
| Propane | Vol% | | 6 | | | | 6 |
| Butane | Vol% | | 2 | | | | |
| Ethane | Vol% | | | | | | 7 |

In Croatia, standard quality natural gas is described in the **Energy Act (NN. 120/12)** and in the **General Conditions of Energy Supply of natural gas – Appendix 1 (NN. 43/2009)**.

Monitoring the quality of natural gas and reporting on the same lies in legislative competence of the transmission system operator Plinacro Ltd. and in the distribution system operator (DSO).

## *7.2 Public transport*

Ministry of the Interior in agreement with the Ministry of Environmental Protection, Physical Planning and Construction has issued **System Regulation for the supply of motor vehicles with compressed natural gas (NN 134/09)**, which determines safety and technical requirements in design, development, assembly, installation and testing of components and assemblies that form the technical and technological supply system of motor vehicles with compressed natural gas, as well as the implementation of protective measures against fire and explosion.

Supply system for motor vehicles with CNG, within the meaning of above-mentioned Regulation, is the part of the station for motor vehicles supply with CNG on which the system for the supply of motor vehicles with CNG is positioned. It consists of technical and technological unit which performs refuelling of vehicles at the location of the station, or equipment used at the location for pressurization, storage or further preparation of natural gas, and furthermore it is then delivered in a state of drive fuel required for the supply of motor vehicles powered by CNG into car tanks.

This Regulation prescribes that the system for supply of motor vehicles with CNG, including all components of the filling stations for motor vehicles with CNG, from the input flange at the connection point with the supply pipeline to the vehicle filling connectors, is assembly constructed in accordance with applicable regulations of the pressure equipment and Croatian standards related to their application.

Also, this Regulation prescribes the safety and technical requirements in design, manufacture, assembly, installation and testing of components and assemblies which are filled under pressure on vehicles with nominal (normal) filling pressure of 20 MPa (200 bar) at a temperature of 15 °C. Conditions are related to the supply systems of motor vehicles with CNG with a total maximum capacity of compressor more than 10 $m^3/h$ (working within the design parameters of the system) and/or with the maximum compressor pressure higher than 20 MPa (200 bar).

Built-in compression devices must provide a possibility of safe and continuous operation of the system for the supply with CNG. Each compressor should have an appropriate mechanism for protection against excessive pressure pulsations. In the case of power failure each compressor must independently be shut down safely. A safety valve with adequate relief capacity should be fitted at the output of the compressor. Gas temperature at the output of each compressor should not damage the implanted devices. Construction of the compressor must be in accordance with the zone of danger area potentially endangered by explosive atmosphere in which they are situated. Operating temperature must be monitored (switch in the case of unallowed temperature).

When filing the tank under pressure in vehicle, safety mechanism of CNG system should enter into operation at the time (no later) of reaching the maximum allowable working pressure. For vehicles powered by natural gas which are filled with CNG and whose tanks suit the requirements for installation in the vehicle according to the document UNECE-R-110 or 84/525/EEC, maximum allowable pressure when filling the tank must be matched with following (it is not allowed to exceed):

- Pressure of 20 MPa (200 bars) in terms of the steady state of gas in the vehicle tank at a temperature of 15 °C.
- Pressure of 26 MPa (260 bar) which may result in case of the maximum expected temperature regardless to the ambient temperature

In cases where the supply system for motor vehicles with CNG is installed at the location where ambient temperatures exceed 30 °C, the maximum allowable pressure when filling the vehicle must be adapted to the pressure of 26 MPa (260 bar) – this pressure should not be exceeded over a temperature of 65 °C (e.g. at the temperature of minus 40 °C filling pressure should be limited to 18 MPa).

Vehicles powered by natural gas whose tanks do not meet the requirements of the UNECE-R-110 or 84/525/EEC are filled with special precautions.

Connector for filling must be set in such a way that it allows fast and safe separation from the vehicle at any moment. Filling connectors that meet the requirements for installation must be in accordance with **ISO 14469-1:2004**. Filling adapter must meet the requirements for pressure equipment and own label with maximum allowable working pressure.

Protective enclosures must tolerate expected (predictable) mechanical stress and meet requirements with regard to aging. They must be constructed from the non-combustible materials in class A1 or A2,-s1, d0 according to **EN 13501-1**.

Structural elements must be made of materials resistant to fire or with a fire resistance of at least 90 minutes. The same applies to the non-structural elements, doors and openings. The fire resistance of 90 minutes shall be determined in accordance with standards mentioned at the end of this section.

Requirements of the Regulation (NN 134/09) may also be applied to systems with a higher filling pressure, taking into account the safety of the components, i.e. safety distances, mechanical strength and ensure the safety of installation of pressure equipment.

Regulation includes all equipment built into the system for the supply of motor vehicles with CNG starting from input flange to outlet connector for filling, associated buildings and facilities and traffic areas. Holes on connectors for the supply of motor vehicles with CNG at the station are considered as the endpoint to which these conditions apply.

Any project should be developed in accordance with the design solution and the applicable regulations in Croatia and in accordance with Croatian and other worldwide recognized norms and standards.

The International Standard (ISO 11439:2000) specifies minimum requirements for serially produced light-weight refillable gas cylinders intended only for on-board storage of high pressure compressed natural gas as a fuel for automotive vehicles to which the cylinders are to be fixed. The service conditions do not cover external loadings which may arise from vehicle collisions, etc. This International Standard covers cylinders of any steel, aluminium or non-metallic material construction, using any design or method of manufacture suitable for the specified service conditions. This International Standard does not cover cylinders of stainless steel or of welded construction.

ISO 14469-1:2004 (NGV standard) specifies CNG refuelling nozzles and receptacles constructed entirely of new and unused parts and materials, for road vehicles powered by compressed natural gas. A CNG refuelling connector consists of, as applicable, the receptacle and its protective cap (mounted on the vehicle) and the nozzle. ISO 14469-1:2004 is applicable only to such devices designed for a service pressure of 20 MPa (200 bar), identified by the code B200, to those using CNG in accordance with ISO 15403 and having standardized mating components, and to connectors that prevent natural gas vehicles from being fuelled by dispenser stations with service pressures higher than that of the vehicle, while allowing them to be fuelled by stations with service pressures less than or equal to the vehicle fuel system service pressure.

List of other relevant standards is given below.

- HRN EN 60079-10 Classification of endangered areas – Explosive gas atmospheres
- HRN EN 60079-14 Explosive atmospheres. Part 14: Design, selection and execution of electrical installations
- IEC 1340-4-1 Floor covering evaluation
- HRN EN 1127-1 Prevention and explosion protection. Part 1: Basic concepts and methodology)
- HRN EN ISO 13943 Protection against fire.
- HRN EN 13501-1: 2002 Classification of construction products and elements due to the behaviour in case of the fire. Part 1: Classification based on the reaction to fire.
- HRN EN 1364-1 Fire resistance tests for non-structural elements. Part 1: Walls.
- HRN EN 1364-2 Fire resistance tests for non-structural elements. Part 2: Ceilings.
- HRN EN 1365-1 Fire resistance tests for structural elements. Part 1: Walls.
- HRN EN 1365-2 Fire resistance tests for structural elements. Part 2: Floors and roofs.
- HRN EN 1366-1 Fire testing of service installations. Part 1: Channels.
- HRN EN 1366-2 Fire testing of service installations. Part 2: Fire dampers.
- HRN EN 1634-1 Fire resistance tests for doors and shutters.

## *7.3 Recommended amendments*

### 7.3.1 Grid injection

Related to biomethane, grid injection recommendations from Germany should be followed, and are represented with:

- For the injection of biogas into gas transmission grids no connection fees have to be paid.
- Biomethane injection fee: the owner of biogas at the point in time when biomethane is injected into the grid should get a fee that will allow him to operate the biomethane facility with appropriate revenue (in Germany of 0.7 Cent/kWh) for “avoided grid costs” by the grid operator of that grid in which biogas is injected. It should be paid for minimum 10 years beginning from the start of an operation of grid access, and should be independent on the grid level (e.g. pressure level).
- Following cost fractions (for grid access) should be divided among all grids (and therefore among natural gas customers that are connected to these grids):
    - Costs for grid connection as well as for maintenance and operation.
    - Potential costs for financially reasonable measures for an increase in grid capacity to be able to ensure biogas grid injection over the whole year. This can also include costs for reverse feeding/compression of natural gas of grids with lower pressure levels, respectively capacities, to grids with higher pressure levels.
    - Costs for advanced (biogas) balance management minus fees for advanced balance management that have to be paid by the responsible person for a balance group.
    - Costs for gas conditioning, odorization and gas constitution measurement.
    - Fees for “avoided grid costs”.

The Government should set a target for future biomethane production that should be subsidised by the proposed measures.

Rule for the priority access of biomethane to gas grids should be established: grid operators have to ensure that transport contracts are concluded with a priority consideration with transport customers of biomethane.

The components that should be considered as biomethane grid connection should be defined:

- Connection pipe between upgrading plant and gas supply grid
- Gas pressure regulation measurement equipment
- Feature for pressure increase
- Calibratable measurement equipment for biogas
- Equipment for the addition of odorants
- Gas conditioning equipment (e.g. for the addition of LPG)
- Gas constitution measurement

Gas grid operator should participate in investment costs of the grid connection aider in full amount or with a certain percentage.

The grid operator should be responsible for maintenance and operation of the grid connection station and has to cover the costs for these tasks.

The grid operator has to ensure a permanent availability of the grid connection station.

The person who is injecting the gas has to ensure that biomethane quality corresponds to the requirements of General Conditions of Energy Supply of natural gas.

### 7.3.2 Public transport

Related to the System Regulation for the supply of motor vehicles with compressed natural gas (NN 134/09) and related spatial planning regulation, amendments related to filling stations with working capacity of more than 10 m³/h should be considered. The filling stations for public use and for investor’s own use should be considered differently. According to the current regulation, the development of investor's own use filling station should follow the same procedure as one for the public use. This means that procedure related to the building of a petroleum project filling station should be followed (changes in spatial plans, fulfillment of defined minimum distances and similar) which is very complicated and it resulted in abandonment of the planned project by one investor. The procedure for development of the investor's own use filling station should be simplified as much as possible but taking into account that safety requirements are met.

Whole sets of other measures could be implemented with the final goal of reaching the use of biomethane or CNG in public and civil transport.

**Motivation by own example and use of non-technical measures**

Motivation by own example

Encouragement by example means the use of vehicles powered by compressed natural gas in fleet vehicles of local, regional and national government. Companies for distribution of natural gas also belong among the companies that are today mainly owned by local governments.

Among non-technical incentives (and based on existing European models) the following could be included:

- Free parking for vehicles that use alternative fuels, meaning environmentally friendly vehicles, including natural gas vehicles.
- For taxis - the advantage of waiting in line for passengers compared to taxis using classic fuels.
- Allowing vehicles on natural gas to park in areas where access is restricted to all other vehicles (eg. access to delivery vans on natural gas in the old town).
- Favourable treatment of other transport companies who use measures for clean environmentally friendly transport in their fleet (through a variety of non-technical and non-financial benefits, like the previous example).

**Tax policy measures**

Tax policy measures also cover certain activities at the level of vehicles, namely fuel:

- Lowering taxes and excise duties for corporations in procurement of vehicles for official purposes. Given that the vehicles powered by compressed natural gas are more expensive than their equivalent models on gasoline or diesel fuel in this way it is possible to reduce or cancel the above differences in investment. Considering that in the initial stage the number of vehicles, especially for the fleet owned by corporations, won't be very large compared to gasoline or diesel fuel, there won't be a significant reduction in income tax and excise duties (especially because the complete abolition of taxes and excise duties hasn't been proposed, but only parts of them).
- Neutral tax measures for natural gas as a fuel for power of motor fuels, ie. release from the introduction of taxes on $CO_2$ emissions in case of its introduction in the price of other fuels.
- Guaranteed (and long enough) period in which the natural gas as a fuel for motor vehicles power will be exempt of taxes, excluding value added tax. Regarding the last point, a favourable difference in the price of natural gas in relation to motor fuels (gasoline and diesel fuel) is already present, but measures are necessary for its retention in the predetermined time period.

**Correction of the associated charges for natural gas vehicles**

In Croatia, while registering a reconstructed gas power vehicle (or the original factory-produced natural gas vehicle), an additional fee is paid for road tolls in the amount of 550kn for cars and 2,000kn for trucks.

Therefore it is necessary:

• To balance the charges for natural gas vehicles with furniture vans and light commercial vans, i.e. equate them with the amount for passenger cars.

**Dedicated financial incentives to projects using natural gas in transport by Environmental Protection and Energy Efficiency Fund**

- Active role of the Environmental Protection and Energy Efficiency Fund and an increase in the proportion of funds collected from the transport sector in the form of earmarked funds that are returned back to the transport sector.
- Correction of the coefficient depending on the type of engine and fuel, which is part of the equation that determines the amount of environmental charges in terms of its reduction.

**Drafting legislation and regulations related to garages**

One of the main issues related to the use of buses powered by compressed natural gas is the possibility of their entrance into the existing garage (for maintenance of diesel buses) for daily and routine maintenance and unscheduled repairs, in other words operations needed to be carried out from safety standpoint. It is necessary to point out the claims of all bus manufacturers and the experience of public transport operators who use them, that natural gas buses are as safe as, if not safer, the buses on diesel fuel considering a relatively narrow area of explosiveness of mixtures of gas and air, and natural gas is lighter than air and is not retained in the workspace.

Below, as an example, we list activities carried out in the garage for maintenance of diesel bus operators of public transport in Torino, in order to accept natural gas buses: setting up partitions and separation of work space in order to provide structural resistance to flame (for 120 minutes) - all the interior doors or doors that are used for communication with other parts of the garage must have 120 minutes fire resistance coefficient, the front door must be open under normal conditions, some skylights must be modified in order to be able to ensure their openness; installing ventilation towers for the provision of three air changes per hour in the roof section, installing a system for detecting gas leaks associated with ventilation towers and front doors to ensure air circulation for forcing natural gas through the roof vents.

In case of a request by the Department of fire protection, a heat detection device can be installed.

The proposed measure, which is one of the preconditions for development of use of natural gas powered buses (primarily public transport), is:

- Development and adoption of regulations related to garages for maintenance of buses to be able to accept natural gas buses as well (in addition to diesel buses).

**Encouraging the development of "blue corridors"**

The term "blue corridor" entails the network of filling stations distributed primarily along major roads and highways, which allows transit through several countries without having to use any other fuels apart from natural gas.

Proposed activities in the Republic of Croatia in that direction are:

- Development of blue corridors at existing gas stations for fuel supply of motor vehicles or filling stations close to major highways and motorways - the development by gas industry with promotional measures by the state meaning local governments leading by example (use of vehicles powered by compressed natural gas in their driving park, along with filling at those stations).
- Involvement of large gas company in development of "blue corridors", i.e. showing confidence in the project of natural gas use in transport and also encourages trust and beneficiaries into the project.

- Marketing activities by gas companies as promotion of new technologies and possibilities of gas use.

**Encouraging joint procurement of vehicles**

To encourage joint procurement of natural gas vehicles, marketing activities are required along with conducting audits to introduce fleet operators owned by companies and operators in local city bus transport as well as utility companies with technical, economic and environmental aspects and possibilities of natural gas use for motor vehicles in their fleet, as well as the existing legislative framework.

Interest of individual vehicle manufacturers, who have natural gas vehicles in their production program, should be encouraged through joint procurement of vehicles by merging multiple corporations for achieving sufficiently large orders, which would be interesting for them (in this case they must provide needed service and spare parts).

**Marketing activities and education**

In order for these measures to have satisfactory results, it is necessary to use promotional and marketing activities, as well as educating companies and individuals about the use of natural gas in transport.

- Conducting marketing campaigns and education together with the implementation of the above measures.

# 8 Actors involved in the biomethane supply chain in City of Zagreb

Three branches of Zagreb Holding deal with waste management in the city of Zagreb – City Waste Disposal (waste management), ZGOS (depot for non-hazardous waste, Prudinec, recycling waste, and disposal of municipal and other waste) and Zrinjevac (composting). Biogas production can be organized either as an activity of one of these or some new subsidiaries / companies under whose authority the project of collecting, sorting and using waste will be within the company / subsidiary or as a separate company / subsidiary that will take over the biodegradable fraction of waste and produce biogas, namely biomethane.

For the mentioned company it is required to obtain a license for carrying out energy gas production, and according to the activity, certain conditions must be ensured with appropriate organizational legal form.

We suggest that biomethane manufacturer provides the market through long-term contracts with the largest supplier of natural gas in the City of Zagreb: Zagreb City Gas Works - Supply. These long-term contracts will provide the possibility of better funding and potentially the possibility of project financing of biogas / biomethane plant itself. Zagreb City Gas Works - Supply will take over biomethane through the distribution network and deliver it to the final consumer / consumers where the greatest benefits can be achieved in terms of obligations related to renewable energy sources in the City of Zagreb. This is primarily ZET for gas powered buses which enables the increase in the share of biofuels in public transport with multiplying factor of 2, and other public functions that are required to use renewable energy sources.

It is predicted that ZET and other public offices / businesses will be the ultimate users of biomethane supply chain in Zagreb.

# 9 Proposal of best solutions of biomethane use in City of Zagreb

Given the relatively high production cost of biomethane and the distance of potential biomethane production sites from the main centres of consumption, an injection of biomethane into the high-pressure distribution system of the City of Zagreb and its use as a transport fuel is proposed. Biomethane produced from waste in the balance of biofuels for transport is recorded twice, and as such can have a significant role in achieving the goals of biofuels in transport (up 9.81% at the national level by 2020). Public city transport and the existing 60 natural gas buses, existing natural gas filling stations and filling stations under construction guarantee safe consumption for most of the produced biomethane, while the eventual surpluses could be spent in other public functions that use natural gas.

# 10 Strategy for a biomethane project in City of Zagreb

Four scenarios of biomethane production have been considered:

S1 - Total estimated amount of biowaste in Zagreb - WP3 City Waste Disposal Zagreb

S2 - Reaching IEE UrbanBiogas target by 2020 - 70% of biodegradable waste

S3 -Reaching the goals related to obligations under the Landfill Directive for the City of Zagreb

S4 - Separation of biodegradable parts suitable for AD at the Center for Waste Management

Biogas production, depending on the reference scenario for waste collection, will amount to between 1.1 for scenario S1 and 6.95 million $m^3$ of biomethane for scenario S4 in 2020. The minimum observed quantity of gas is about 4 times lower than the expected consumption of natural gas in ZET's public transport. Calculated maximum volume of 6.95 million $m^3$ of biomethane represents only about 2 percent of the total final energy consumption of gas in the City of Zagreb. But it also should be noted that the above-mentioned potential production is 8 times higher than the consumption of natural gas in Zagreb's traffic and possibly sufficient for 60 existing ZET buses.

Although the total annual production of biomethane from scenario 4, including the IBW, would be sufficient for fuelling ZET bus fleet, hourly biomethane production of maximum 909 $Nm^3$ / h is not sufficient (2700 $Nm^3$ / h is needed). Based on these results we can conclude that the development of a fuelling station at the production site is technically unfeasible (insufficient capacity and fuelling infrastructure already exist at other location). The injection of biomethane in the natural gas network is proposed.

Transmission and distribution pipeline network is developed in Zagreb.

Operating pressure of transmission gas network is 50 bar, while three levels of pressure are available at the distribution system:

- high pressure: 6 bar
- middle pressure: 3 bar
- low pressure: 100 mbar

The connection cost to a high pressure gas network is, depending on the plant location for the production of biomethane, 15 to 60% more expensive than the connection to a medium or low pressure gas network.

Connection to the gas transport network is 2 to 15 times more expensive than the connection to the gas distribution network, depending on the location of the plant for the production of biogas.

Direct connection of Dubrava garage by high pressure pipeline to potential sites of biomethane production is 2 to 6 times more expensive than the plant's connection to the high pressure gas distribution network.

According to the lowest cost criterion, it could be assumed that the connection to the gas distribution network of medium or low pressure would be the most preferable option. However, the city of Zagreb has extremely developed high pressure gas network, to which bigger consumers with even annual gas consumption are mostly connected. High pressure gas network supplies medium or low pressure relatively small "islands" of consumption with gas to which households that have markedly seasonal consumption characteristics are mostly attached. At those medium or low pressure areas, natural gas consumption during summer months is several times lower than the average annual or maximum winter hourly consumption, and may be below the expected hourly consumption of biomethane plants, so the excess gas during this period should either be stored or flared.

Given that the difference between the investment difference at medium / low pressure and high pressure gas distribution system is not significant, and that biomethane by injection into a high pressure gas network will be available throughout the city, injection of biomethane into a high pressure gas network is proposed. Water scrubber or PSA technology with the working pressure above 6 bars is proposed as the technology for purification of biogas to biomethane.

The potential cost of biomethane at the connecting pipeline depends on the specific cost of waste collection and processing, production and purification of biogas to biomethane.

Considering that the concept of waste disposal was created in scenarios, and for that reason it was too complex to calculate the cost of biogas, in this section we are going to use specific prices from Germany increased by 30% (the impact of developing markets and lack of technology). In this way, the calculated cost of biomethane would amount to 0.5 - 0.7 kn / kWh.

The price of gas distribution and injection into natural gas distribution network would, according to the simplified calculation (simple return of investment in 10 years) for the expected production of biogas, be 0.007-0.035 kn / kWh (depending on the production scenario and the distance of location from the gas network).

The price of biomethane at the entry to gas distribution network would amount to between 0.51 and 0.74 kn/kWh. The above price is considerably higher than the price of natural gas at the entry to the gas distribution network, which is about 0.24 to 0.37 kn / kWh.

The expected investment for the construction of one natural gas filling station at Podsused location amounts to approximately EUR 1 million for the first phase, and the total investment for the first and second phase might be between 1.5 and 1.7 million. A detailed economic and financial analysis related to the use of compressed natural gas in the area of Zagreb has been conducted. The cost of construction, operation and maintenance of the filling station, depending on capacity and level of utilization, is between 0.06 and 0.14 kn / kWh.

The price of gas distribution in the city of Zagreb is 0.039 kn/kWh. Based on the above-mentioned indicators, the total price of biomethane at the exit of the filling station would amount to between 0.61 and 0.91 kn/kWh, excluding VAT. The above price is in its smaller amount lower than the cost of diesel fuel or gasoline, but in its larger amount it is higher than the price of motor fuel.

All things considered, it is obvious that it is necessary to encourage the production of biomethane and to remove potential barriers for its implementation. Based on the analysis of legislative environment it can be concluded that there are no barriers for biomethane access to gas transmission or distribution network. Pipeline access is guaranteed to all types of gas that can be safely transported by gas network and meet the General terms and conditions for natural gas supply as well as prescribed gas quality requirements.

Although the benefits of using biomethane produced from waste in transport have been recognized at national and local level (share of biomethane is administratively recorded twice), the largest barriers to its implementation are set at that same level.

Although the existing biogas production today is already higher than the planned production levels for 2020 (according to the National Action Plan to encourage the production and use of biofuels in transport for the period of 2011-2020), the adoption of incentives for the use of biomethane in transport (Decree on the promotion of biogas production for transportation and admission of using biogas in the promotion of the use of compressed natural gas for transportation) is predicted only for the period after 2016. With the purpose of successful application of biomethane in transport it is necessary to remove the barriers set by the National Plan as soon as possible and provide adequate support for the use of biomethane in transport.

At the local level, the most significant barriers are stipulated by regulations from spatial planning documentation. For construction of gas stations for the supply of motor vehicles same regulations are applied as for the construction of petrol stations. These regulations are certainly acceptable and desirable for public gas stations, but have a negative impact on the possibility of building a gas station for own use. Filling station for public use and own use should be considered differently. According to the current regulation, the development of own use filling station should have the same procedure as one for the public use. This means that the procedure related to the building of a petroleum project filling station should be followed (changes in spatial plans, fulfilment of defined minimum distances and similar) which is very complicated and it resulted in abandonment of a planned project by one investor. The procedure for development of own use filling station should be simplified as much as possible but taking into account that safety requirements are met.

Biogas production can be organized either as an activity of one of the three branches of Zagreb Holding that deal with waste, or some new subsidiaries / companies under whose authority the project of sorting and use of waste will be. Biomethane production can be organized with specific companies / subsidiaries that will take possession of the biodegradable fraction of waste and produce biogas, namely biomethane.

It is essential that producers of biomethane obtain a license for carrying out energy activities in natural gas production.

We suggest that biomethane manufacturer provides the market through long-term contracts with the largest supplier of natural gas in the City of Zagreb: Zagreb City Gas Works - Supply. These long-term contracts will provide the possibility of better funding and potentially the possibility of project financing of biogas / biomethane plant itself.

Zagreb City Gas Works - Supply will place the taken over biomethane to that segment of customers who have the greatest benefit of biomethane use: public transport and similar public functions.

Due to relatively high costs of biomethane it is necessary to provide an appropriate support mechanism at the national level. Potential benefits of biomethane production from waste and its use are manifold, and in addition to ensuring sustainable and clean fuel, it provides achievement of objectives about the share of organic waste in landfills and the share of biofuels in transport.

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